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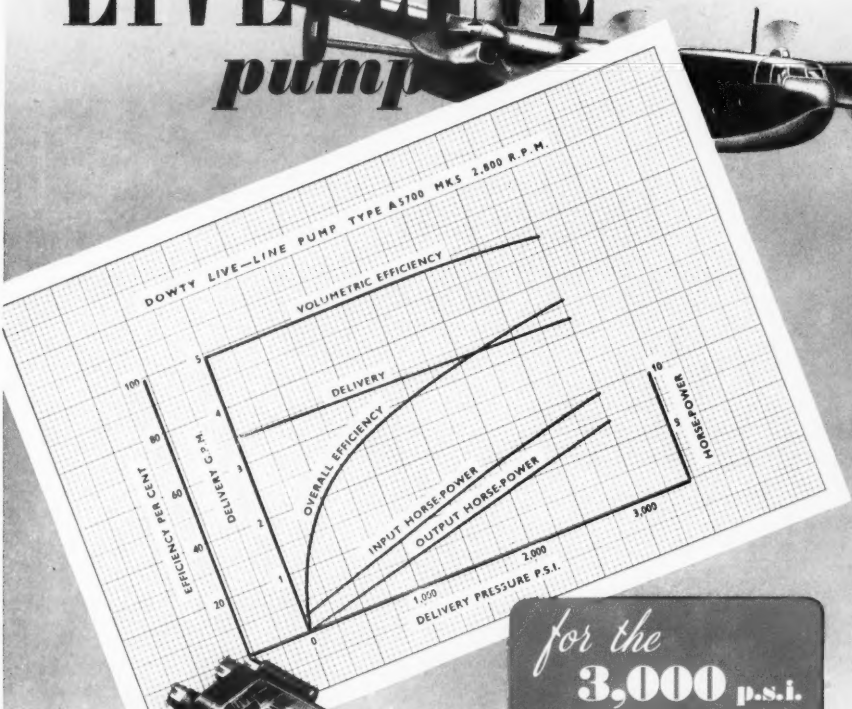
The Journal of
THE ROYAL AERONAUTICAL SOCIETY

APRIL 1947 · NO 436 · VOL 51

DOWTY LIVE-LINE pump



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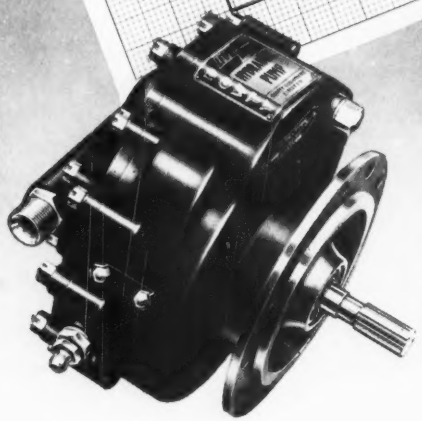

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APRIL NOTICES 1947

JOURNAL PREMIUM AWARDS

The Council have set aside an annual sum of £250 for the award of premiums for papers published in the *Journal* and the Council hope that members (or non-members) will contribute papers on their own special subjects.

CONTENTS OF THE APRIL JOURNAL

The Development of the Spitfire and Seafire, by J. Smith, C.B.E., F.R.Ae.S., A.M.I.A.E.

Development of Air Transport during the War, by Air Marshal the Hon. Sir Ralph Cochrane, K.B.E., C.B., A.F.C.

Mechanical Vibration and Aeroelasticity, by P. B. Walker, M.A., Ph.D., F.R.Ae.S.

LECTURES—ADVANCE PROOFS

Because of the severe restrictions on paper and the difficulties of printing caused by the fuel crisis, there will be no advance proofs of Lectures given before the Society during the present Session, that is, up to the end of May.

In future a brief résumé of forthcoming lectures will be published, whenever possible, in Monthly Notices or the Journal.

Summaries of some of the forthcoming Lectures are given elsewhere in these Notices.

LECTURE PROGRAMME—SPRING SESSION 1947

Except where otherwise stated, the lectures will be held at 6 p.m. in the Lecture Hall of the Institution of Civil Engineers, Great George Street, S.W.1 (by permission of the Council of the Institution). Tea will be served at 5.30.

Visitors are welcome, but should obtain tickets through a member of the Society.

Thursday, 10th April, 1947—A Review of Production Problems in Relation to Aircraft Design, by Mr. C. E. Fielding, O.B.E., A.F.R.Ae.S., M.I.P.E.

Thursday, 17th April, 1947—Testing Civil Aircraft, by Mr. P. A. Hufton, M.Sc.

Thursday, 24th April, 1947—Prevention of Fires in Aircraft, by Dr. J. W. Drinkwater, D.Phil., B.Sc., Wh.Sc., and Mr. W. G. Glendinning, B.A., B.Sc.

Thursday, 1st May, 1947—The Development of the A.S. type Gas Turbine, by Mr. W. H. Lindsey, M.A., A.F.R.Ae.S.

DISCUSSION ON NAVAL AIRCRAFT

Wednesday, 7th May, 1947—A full-day Discussion will be held at which the following papers will be read:—

Morning Session

11 a.m. A Survey of the Technical Problems of the Design of Naval Aircraft, by Mr. W. S. Farren, C.B., M.A., F.R.S., F.R.Ae.S.

12 noon. Equipment, by Mr. L. Boddington.

1-2.30 p.m. Luncheon Interval.

Members and visitors should make their own arrangements for lunch.

Afternoon Session

2.30 p.m. Operational Flying, by Commander F. M. A. Torrens-Spence, D.S.O., D.S.C., R.N.

3.30 p.m. Films illustrating Deck Landing, shown by Mr. W. G. A. Perring, F.R.Ae.S.
4.30-5 p.m. Tea Interval (tea provided).

Evening Session

5-6.30 p.m. General Discussion and summing-up by the Chairman.

Thursday, 8th May, 1947—The Development of the Goblin Engine, by Mr. E. S. Moult, B.Sc., A.M.I.Mech.E., A.F.R.Ae.S.

Thursday, 29th May, 1947—The Thirty-Fifth Wilbur Wright Memorial Lecture will be read by Mr. J. K. Northrop.

BRANCH LECTURES AND NOTICES

BIRMINGHAM BRANCH

22nd April, 1947—JOINT MEETING WITH COVENTRY BRANCH. Debate—That the Aircraft of the Future will be Tailless. At the Birmingham Chamber of Commerce, at 7 p.m.

BRISTOL BRANCH

15th April, 1947—Annual general meeting and film show.

All meetings are held in the Conference Room, Filton House, Bristol Aeroplane Co., Ltd., Filton, at 5.30 p.m.

BROUGH BRANCH

9th April, 1947—Jet Propulsion Development, by G. B. R. Feilden, M.A., A.M.I.Mech.E. (Joint Lecture with the Hull Association of Engineers). In the Y.P.I. Lecture Hall, George Street, Hull, at 7.30 p.m.

25th April, 1947—Some Problems of High-Speed Flight, by S. C. Redshaw, F.R.Ae.S. In the Technical School Lecture Room, Blackburn Aircraft Ltd., at 5.30 p.m.

DERBY BRANCH

29th April, 1947—CONVERSAZIONE, at which Group Captain Donaldson will be present. In the Rolls-Royce Welfare Hall, Nightingale Road, Derby, at 6.30 p.m.

GLASGOW BRANCH

8th April, 1947—" Lecturettes." At the Central Hotel, Glasgow, at 7.30 p.m.

LUTON BRANCH

7th May, 1947—Pneumatics for Aircraft, by Group Captain C. S. Morice.

4th June, 1947—Fuels and Oils for Aircraft Turbines, by Dr. C. G. Williams, Ph.D., M.I.Mech.E., F.Inst.Pet., A.F.R.Ae.S.

Meetings are generally held at the George Hotel, Luton, at 7 p.m.

READING AND DISTRICT BRANCH

7th May, 1947—Propeller Turbine Installations, by Mr. A. C. Clinton, F.R.Ae.S., of the Bristol Aeroplane Co. Ltd.

28th May, 1947—FREE FOR ALL. At this meeting any member of the Branch may speak for about 10 minutes on any aeronautical subject. Please let the secretary know beforehand of your intention to speak.

All Lectures are held at 6 p.m. in the Monthly Staff Dining Room, Miles Aircraft Ltd.; tea will be served from 5.30 p.m.

SOUTHAMPTON BRANCH

9th April, 1947—An Address by E. F. Relf, C.B.E., F.R.S., F.R.Ae.S.

All Lectures are held at 7 p.m. in the Physics Lecture Theatre, University College, Southampton.

SUMMARIES OF LECTURES

As stated elsewhere, advance proofs of Lectures for the Spring Session 1947 will not be available. The following are brief summaries of some of the lectures to be read during the next few weeks:—

To be given on 10*th April,* 1947.

"A Review of Production Problems in Relation to Aircraft Design," by C. E. Fielding, O.B.E., A.F.R.Ae.S., M.I.P.E.

In my lecture I was asked to emphasise the wartime experience in aircraft factories and as wartime conditions alter the relative importance of the various problems involved, my approach to this subject has been adjusted accordingly.

Because of the urgent necessity to produce aircraft quickly in wartime, the production engineer has a greater influence on design than normally and many design problems are usually settled by a compromise between the requirements of the designer and the production engineer.

The designer attempts to satisfy the aerodynamic requirements at the lowest possible weight and the production engineer has to consider shop equipment and floor space available, type and availability of labour and ensure that the aircraft can be built in a minimum of man-hours.

Apart from the necessary breakdown of the aircraft into its various components for transport and servicing purposes, considerable advantages can be gained by giving special consideration to the equipping and assembly problems.

The fuselage sections should be designed so that each section can be completely equipped before joining together.

It should also be possible to break down the fuselage equipment into bench assemblies and easily fit it in the fuselage.

To get a maximum benefit from this unit construction, electrical services should terminate at a plug and socket and flying controls, hydraulic services and so on, should have an easily accessible joint.

Detail design should be as simple as possible and be within the scope of the shop equipment available and must also lend itself to satisfactory sub-assembly.

Structures and sub-assemblies should also be kept as simple as possible and the numbers of different details kept down to a minimum.

Interchangeability is another important requirement and should be settled in the early stages of design as, in addition to providing for efficient servicing, it speeds up assembly.

To be given on 17*th April,* 1947

"Testing Civil Aircaft," by P. A. Hufton, M.Sc.

The author covers the present position in flight testing of civil aircraft and the probable future changes. He surveys the basis for the tests which are made at the Aeroplane and Armament Experimental Establishment, Boscombe Down, discussing the interpretation of existing regulations, the need for new regulations and the organisation required to minimise the testing time.

In addition to the preparatory tests the functioning, handling, performance, take-off and landing and cooling tests are examined. The fundamentals of the "engine-cut" take-off

are considered in detail and it is shown how the various regulations fit into the general scheme for supplying sufficient information to allow operators and pilots to attain a reasonable level of safety. It is suggested that the immediate aim should be an accident rate giving a figure of not more than one accident every ten years at any airport. To this end a take-off drill is described which is safe under the following conditions:—

1. The pilot is given figures for climbing speeds and so on at which he can retain control if an engine fails.
2. The operator is given figures for all-up weight of the aircraft for which it "fits," with one engine failed, the airport dimensions and the surrounding country.
3. The general performance of the aircraft with one engine failed is so high that the take-off performance is not "critical" to small changes and errors in atmospheric conditions, weights, pilotage and so on.

The problems of interpreting performance and cooling tests over the range of temperatures from temperate to tropical are described. It is concluded that actual tests under tropical conditions may be essential to obtain accurate information with the more refined reciprocating engines. These tests might be necessary at both high and low altitude airfields and apply in even greater measure to jet-engined aircraft.

Some of the problems confronting the flight testing of the civil aircraft of the future are touched upon and the paper concludes with a discussion on the planning of flight trials.

To be given on the 24th April, 1947.

"Prevention of Fires in Aircraft," by Dr. J. W. Drinkwater, D.Phil., B.Sc., Wh.Sc., and W. G. Glendinning, B.A., B.Sc.

Evidence collected during the war has shown that accidental fires during flight originated mainly in the power plant and followed some partial or complete engine failures or, less frequently, a leakage of fuel, hydraulic fluid or oil. Immediate remedial measures adopted consisted of (1) provision of fire detectors operating warning lights, (2) providing the pilot with the control of the fire extinguisher so that he could bring the engine to rest by feathering the propeller and shutting off the fuel, before discharging the extinguishing fluid, (3) isolation of the fire by fire walls.

Preventive measures are (1) provision of an engine failure warning device so that the engine can be shut down before complete failure occurs, (2) fire-resistant fuel and oil pipes, (3) protection of services essential for stopping the engine and operating the extinguisher, (4) removing fuel and oil pipes from potential sources of ignition, (5) drainage and ventilation in the power plant to prevent accumulation of inflammable fluids or vapours.

Crash fires usually start in the engine and spread to the fuel supply. The extinguishing fluid is discharged by a crash-operated switch and its main function is to blanket and cool the exhaust system. Remedial measures must aim at preventing fuel from reaching the exhaust and should include a crash-proof fuel system. Low volatile fuels, compared with petrol, offer a reduction in fire risk.

The established principles of fire prevention are being applied to the design of turbine-engined aircraft.

The major risks in warfare are ignition of fuel issuing from a damaged tank and explosion of the vapour-air mixture above the fuel in a tank. The former can often be extinguished by an automatic extinguisher around the tank and the latter can be prevented by the use of inert gas above the fuel.

DISCUSSION ON NAVAL AIRCRAFT

The following papers will be read at the full-day discussion on the 7th May, 1947:—

"A Survey of the Technical Problems of the Design of Naval Aircraft," by W. S. Farren, C.B., M.A., F.R.S., F.R.Ae.S.

Some Questions.

(1) What are "Naval Aircraft"?

(2) Do Naval Aircraft differ essentially from land-based aircraft, either in their functions or in their technical make-up?

(3) Will there continue to be Naval Aircraft?

Reasonable agreement on these, with a substantial "yes" to (3) essential for useful discussion.

Aircraft Design in Relation to Advances in Weapons and Radar.

Flexibility and adaptability in the layout of the aircraft the only promising solution.

Naval Aircraft on the Carrier.

(1) Operation from ships leads to an additional set of requirements. The problem of design is to turn them from a burden into an asset. To a solution of this the development of the carrier can and should contribute.

(2) Take-off. "Assistance" has come to stay. It should be developed into "Projection." Aircraft design can do much, but the ship's power should be more fully exploited.

(3) Landing. The aircraft's qualities determined by control and pilot's view. The full potentialities of aerodynamics (flaps, slots, spoilers, suction) still to be exploited. Chief improvement likely to be in control of growth and spread of stall, rather than in development of very high lift. The capacity of the arrester to accept higher speeds should be developed. Need the Naval Aircraft have wheels and a conventional undercarriage?

Economics of Naval Aircraft Design—Radius of Action.

The design of Naval Aircraft dominated by Naval requirement for very large radius of action. The design of power plants should be reviewed to ensure that the economy in fuel consumption attainable under controlled conditions is realised in operations

(1) For turbines and jets, reduction in fuel consumption at cruising power is essential.

(2) For jets, an increase in efficiency of propulsion by entraining additional air would pay a good dividend.

(3) For all types and arrangements of Naval Aircraft, irrespective of power plant, reduction of the drag of the aircraft is of the highest importance.

Conclusion.

The technical problems of the design of Naval Aircraft are essentially the same as those of land-based aircraft, but more difficult. But, given corresponding effort in development of the potentialities of the carrier, equally good and possibly better aircraft can be produced.

"Equipment," by L. Boddington.

The deck operating requirements involve special equipment both on the aircraft and on the deck. The most important requirements concern catapulted take-off with means for rapid handling of the aircraft, assisted take-off by rockets, arrested landings and barrier engagements.

Catapulting is now by the tail-down method and the deck equipment is a ram/rope system. Acceleration characteristics and undercarriage loading are dependent on the elastic system formed by the deck machinery and the aircraft, which is also elastically supported by the undercarriage. The rate of build up of acceleration decides the degree of dynamic loading, and cross-wind launching, combined with ship pitch and roll are important requirements to be met.

Assisted take-off is provided by a suitable combination of rockets using solid propellants.

An arrested landing must be made every time the aircraft returns to the ship. The transverse wires are connected in pairs to the energy dissipating unit through a rope system and the factors controlling the performance of the equipment are elasticity, impact and inertia. Hook installation must be positioned to prevent excessive pitching and give good anti-bounce characteristics through an efficient damper system. The treading down of the arrester wires by the aircraft lessens the chances of picking up.

A barrier engagement will follow failure of the arrester hook, or from aircraft bounce and float. The safety of personnel in the aircraft and on the deck is of first importance and the aircraft should not be thrown over on its back.

In all deck operations, rates of operation are important. Especially so for catapulting which requires special handling arrangements of the deck for the rapid loading of the aircraft.

" Operational Flying," by Commander F. M. A. Torrens-Spence, D.S.O., D.S.C., R.N.

1. The lecture will describe first typical operations in which ship-borne aircraft feature prominently in the current state of weapon development, namely:—

(*a*) The covering of own shipping movements in the face of enemy action by shore-based aircraft, submarine or naval forces.

(*b*) Offensive action against enemy shipping.

(*c*) The deliberate engagement with enemy shore-based aviation at short range to cover a military landing or evacuation.

(*d*) The " set piece " raid against an enemy shore base or special target.

2. In the recent war the majority of British naval air operations were under class (*a*) above. An illustration of (*b*) was the sinking of the Bismarck, but activity under this heading was limited because of the lack of enemy shipping in open waters. Type (*c*) was represented on our side by the landings in French North Africa in 1942, at Salerno in 1943, and in the South of France in 1944; and, on the American side, by the advance right across the Pacific by the successive capture of enemy strongholds. Examples of type (*d*) were Taranto and Pearl Harbour.

3. Against this background the lecturer will discuss:

(*a*) The integration of the aircraft carrier into the strategic naval unit or " task force " (which includes many other types of ship); and the strategic mobility of the whole.

(*b*) The extent of the flying effort which can be developed from one aircraft carrier. The speed of operations from the deck and the equipment employed.

(*c*) An outline of current first-line types and their uses. Replacement types and the trend of development.

(*d*) The relative effectiveness of ship and shore-based aircraft in different circumstances.

(*e*) The indispensability of ship-borne aviation to imperial defence.

To be given on the 8th May, 1947

"The Development of the Goblin Engine," by E. S. Moult, B.Sc., M.I.Mech.E., A.F.R.Ae.S.

The paper covers the development of the de Havilland Goblin jet propulsion engine from its conception in 1941 to the present time. Although the engine was designed at the request of the Ministry of Aircraft Production, the de Havilland Company were given a completely free hand in selecting its size and the features of its design.

New ground was broken in the layout of the engine which incorporates twin, high-velocity intakes, a single-sided impellor for the compressor, straight-through combustion system and complete cantilever suspension in the airframe.

A general description is given of the Goblin engine, which is now in full production, together with an account of the stages of development leading to the Goblin II as installed in the Vampire aircraft. There follows a more detailed examination of the principal elements of the engine and of the problems that had to be surmounted during design and in the course of subsequent development.

The compressor, the turbine and the combustion and fuel systems are dealt with at length and there is some description of the special plant required to test the complete engine and its main components. Information obtained from a calibration of the Goblin engine in the altitude tunnel at Munich was of inestimable value in confirming the results obtained in flight.

The Goblin engine has been fitted to a number of airframes besides the Vampire and was the power plant which first enabled level speeds in excess of 500 m.p.h. to be attained, both in this Country and in America. It was the first gas turbine engine to receive a Certificate of Type Approval and the power plant of the first jet-propelled aircraft to land on and take-off from a ship at sea.

GRADUATES' AND STUDENTS' SECTION

Friday, 2nd May, 1947—Flight Testing of Aircraft, by Mr. W. Humble.

Meetings are held at 7.30 p.m. in the Library of the Society, 4 Hamilton Place, W.1.

ASSOCIATE FELLOWSHIP EXAMINATIONS, 1947 and 1946

Associate Fellowship Examination, May 1947

The next Associate Fellowship examinations will be held from 10 a.m. to 5 p.m. on Tuesday 20th and Wednesday 21st May 1947. All candidates will receive full instructions direct.

Associate Fellowship Examination, December 1946 Additions

In addition to the results given in the March Journal, the following candidates have been successful in the December 1946 Associate Fellowship Examination:—

W. A. Beedie, Pure Mathematics (S.E.A.A.F.); G. Gawthorpe, Applied Mathematics, Navigation and its application to Aeronautics, Aerodynamics (Sydney, Australia).

JOURNAL BINDING

Because of increased costs, the prices of binding of Journals will be as follows:—

1946 Volume 12/6.

Previous Volumes 13/6.

Journals should be sent direct to The Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the office of the Society.

INCOME TAX

In response to numerous inquiries from members with regard to a rebate on Income Tax for their subscriptions, the following is a copy of a letter received from the Principal Inspector of Taxes.

Ref. H.R.S. 34/C.I. 4420/63.

Dear Sir,

Further to your interview with Mr. Stonely at this office on the 19th July, I am now in a position to inform you that the Board of Inland Revenue will not raise objection to the allowance as an expense for Income Tax purposes of annual subscriptions paid by members who are:—

(i) Assessable under Schedule D of the Income Tax Acts in respect of professional or trading profits, subject to the decision of the Commissioners who make the assessment that such subscriptions are sufficiently closely related to the business on: or

(ii) Assessable under Schedule E in those cases only in which continual membership of the Society is an essential condition of the terms of appointment.

Yours faithfully,
(Signed) GEO. WILCOCK,
Principal Inspector of Taxes.

CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Changes of address must be received **before the 15th of the month** in order to be effective for the Journal for the following month.

ELECTION OF MEMBERS

The following new members have been elected:—

Associate Fellows

John Elliston Allen (from Graduate), Walter John Dinnie Annand, William James Armstrong, Edward Geoffrey Barnes (from Associate), George Brewster (from Student), Edward Brown (from Graduate), Ernest George Collins (from Graduate), Teodor Dachowski (from Associate), John Alastair Davies, Edward Thomas Gleed, Herbert Maynard Hackett (from Graduate), William Arnold Horrocks, Lambertus Ludovious Theoderus Huls, Robert Owen Jones, Frederick Horace Bernard Kelson, Frederick William Kennedy (from Graduate), Jack Nolan Cunningham Law, Robert Arthur Letts (from Student), Ian Black Matheson (from Graduate), Henryk Kazimierz Milicer, Wilfred Morris (from Graduate), Hugh Nelson (ex-Associate Member), Lewis Frederick Nicholson, John Frederick Munday Oram, Frank Leslie Peters, William Anthony Porter (from Graduate), Ronald Matthew Arthur Powell, Jan Witold Rabek, Vernon Heath Richards (from Student), Ernest Owen Robertson, Ian Alastair Scott, Robert George Thorne, Frederick Joseph Twiney, Gregory Frank Webb (from Graduate), Ernest Bertram Weston (from Student), Felix Leslie Worn.

Associates

Leslie Alcock (from Graduate), David Thomas Frederick Warwick Baxter, George Bond, Thomas Vincent John Boughton, John Noel Breslin (from Student), Thomas James Bush, Eric Harold Coleman, James Cuthbert Barrington Coleman (ex-Student), Roland Mottershaw Cooke, Raymond Henry Coombs, Arthur Trevena James Crew (from Graduate), William Henry Davies, Edwin Lawrence Gosling, Matthew Greenwood, Clifford Ernest Harrington, Eric Palfreyman Hewson, Ronald Edward Hobday, Ronald William Jackson, Sidney Harrison Johnstone (from Student), George Victor Richard Jones, Victor Tetlow Kilburn, Frederic Ernest William Knight, Douglas Layzell-Apps, Reuben Isaac Little (from Student), Kenneth Lyon (from Student), Richard Frewen Martin, Joseph Murphy, John Dudley Nourse, Aubrey John Raymond Oates, Dudley Bullen Russell, Alan John Salmon, John Richard Garth Thomson, Alan Edward Vause, Gordon Provo Watson, George Brownlee Young (from Student).

Graduates

Thomas Webster Bagshaw, William John Bartlett, John Bryce (from Student), Sydney Buck, Keith Busby, John Tresham Checketts (from Student), Alan Clegg (from Student), Victor William George Curtis, Hendrik de Vries, Stanley Peter John Ellis (from Student), Peter Ebershardt (from Student), Ronald Ferrari, Ronald George Franklin, Frederick James Fuell, Ernest James Grewcock, Arthur Vernon Hawley (from Student), Douglas Gilbert Hitchcock (from Student), Bernard Arthur Holmes, Maurice Jackson, William Trelawney James, Herbert Richard Leather (from Student), Theodore Herzl Nathanson, Derek Gordon Page, Derek John Raney, Alan William Ratcliff (from Student), Duncan Saunders, Eric Smith (from Student), John Guiseppe Stoppa, Wilfred Taylor, George Edwin Thirlwall, Eric Arthur Turner, Thomas Turner, William Cherry Watson (from Student), Leslie Young (from Student).

Students

Patricia Mary Bailey, William Henry Barber, Geoffrey Charles Barlow, Gerald Derek Barnard, Michael Broad, Arthur Charlton, William Andrews Crawford, George Richard Harrison, John Brian Helliwell, Frederick Arthur Hewitt, Frederick William Pillinger, Alan Frederick Proctor, Laurence Braham Rosenbaum, Darroll Stinton, Kenneth Victor Sutton, John Bertram Wood.

Companions

George Winzar Horne (from Student), Alfred Norman Kinkead (from Student).

ADDITIONS TO THE LIBRARY

Pamphlets in italics with location reference following in brackets. Books marked * or ** may not be taken out on loan.

B.a.372.—Book of the Bristol Aircraft. A. H. Lukins (Comp). Harborough. **1946.**

B.c.96/1 and 2.—*Flight of birds, bats and insects. Frank W. Lane. Daily Mail.* **1946.**

BB.a.15.—American Aircraft Construction Handbook. T. A. Dickenson. Harrap. **1946.**

E.c.29.—Properties and Strengths of Materials. Volume III. J. D. Haddon. Pitman. 1946.

L.d.16.—*Civil aircraft navigator's licence (second class). Examination papers, September* 1946. *Ministry of Civil Aviation. H.M.S.O.* **1946.** (**Y.15.iii.**)

L.d.116.—*Notices to Airmen. Nos.* 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60.

N.a.89.—Structure of Metals and Alloys. William Hume-Rothery. Institute of Metals. 1945.

R.c.288.—Winged World. Harry Harper. Gifford. 1946.

R.f.119.—Four Miles South of Kitty Hawk. Warren McArthur Corporation. 1942.

S.e.134.—Battle Stories of the R.A.F. Leonard Gribble. Burke Publishing Co.

S.e.136.—Slipstream. R. Raymond (Editor). Eyre & Spottiswoode. 1947.

T.c.45.—North Polar Flights of Aries.

Part. I.—Narrative.
Part II.—Navigation.
Part III.—Aircraft Performance.
Part IV.—Meteorology.
Part VI.—Communication and Radar.
Part VII.—Photography and Geographic al Data.
Part VIII.—Medical Aspects and Safety Equipment.
Parts IX and X.—Notes on the History o f Arctic Exploration. Bibliography. E.A.N.S. R.A.F. 1946.

National Research Council of Canada—Aeronautical Laboratories

Quarterly Bulletin. Report No. ME. 1946. (4.)

Australian Council for Aeronautics

Report No. 23.—*Temperatures and moisture contents attained by wooden aircraft in service in Australia. W. L. Greenhill.*

Report No. 25.—*Powder metallurgy. H. L. Wain.*

Report No. 26.—*Temperature measurement on a Beaufort aircraft during summer at Alice Springs and Melbourne. G. J. Bailey and F. A. Dale.*

A.R.C. Reports and Memoranda

2012.—*Frequency "admittance" curves for coupled engine crankshaft (torsional) and contra-revolving propeller (flexural) vibrations.' J. Morris.*

2041.—*The buckling of a flat rectangular plate under axial compression and its behaviour after buckling. H. L. Cox.*

2064.—*The effect of mean incidence, amplitude of oscillation, profile and aspect ratio on pitching moment derivatives. J. B. Bratt and K. C. Wright.*

2073.—*An investigation of the flutter speed of an airscrew blade taking into account the chordwise flexibility and the twist of the blade. I. T. Minhinnick.*

2077.—*Compressible flow in a convergent-divergent nozzle. G. Temple and Jennifer Yarwood.*

Smithsonian Institution

The New England hurricane of September 1944. *C. F. Brooks and C. Chapman.*
Human problems in military aviation. Detlev W. Bronk.

The following reports have also been received:—

Institut fur Flugzeugstatik und Flugzeugbau No. 1.
Monografie Scientifiche di Aeronautica No. 3.
British Intelligence Objectives Sub-Committee.

B.I.O.S. Final Report No. 1117, Item No. 30. No. 513. Item No. 30.
F.I.A.T. Final Report No. 575.
Combined Intelligence Objectives Sub-Committee.
Item No. 21. File No. XXXIII-21.

J. LAURENCE PRITCHARD,
Secretary.

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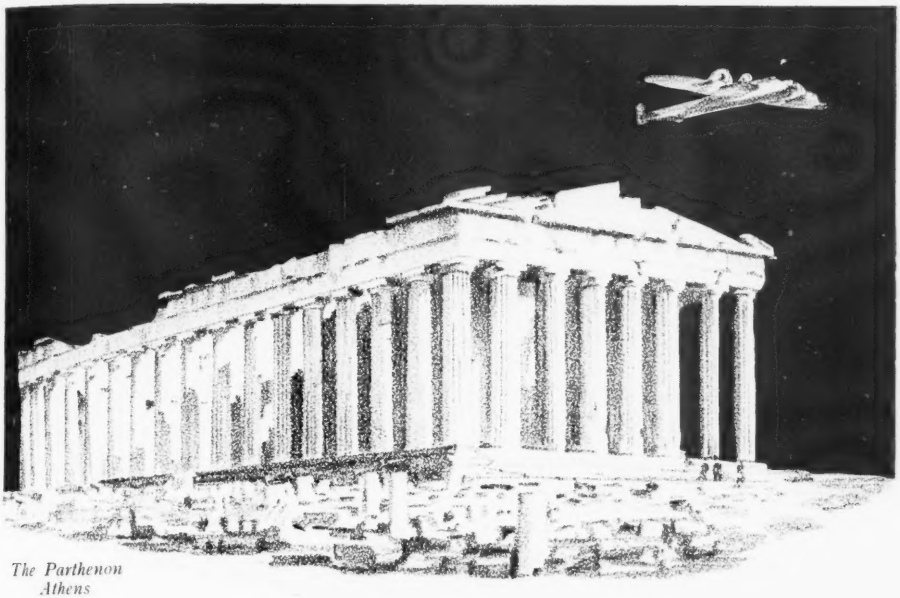

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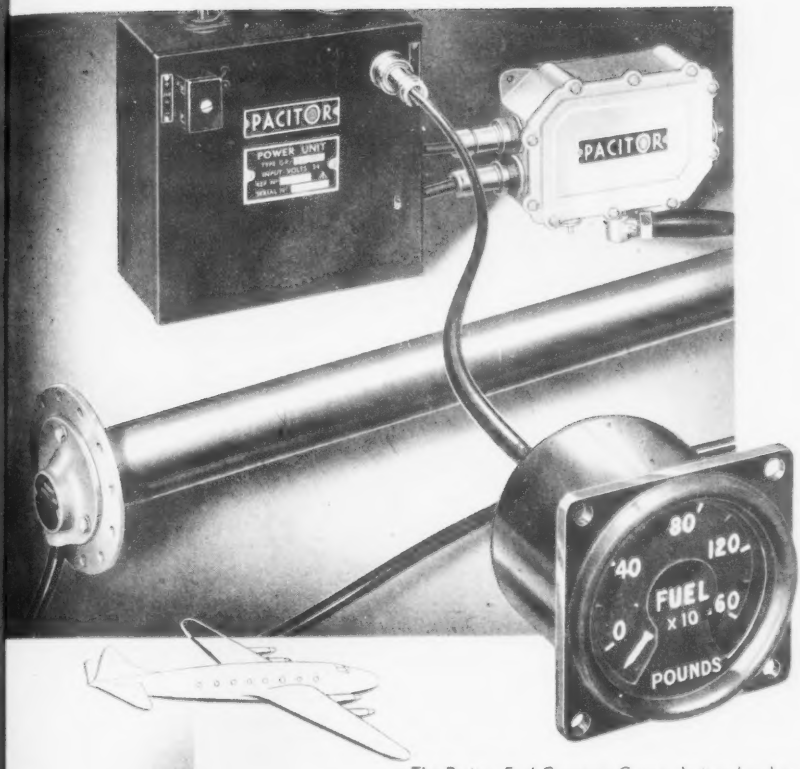

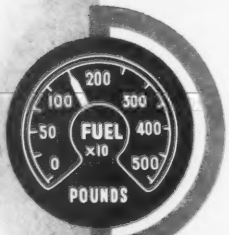

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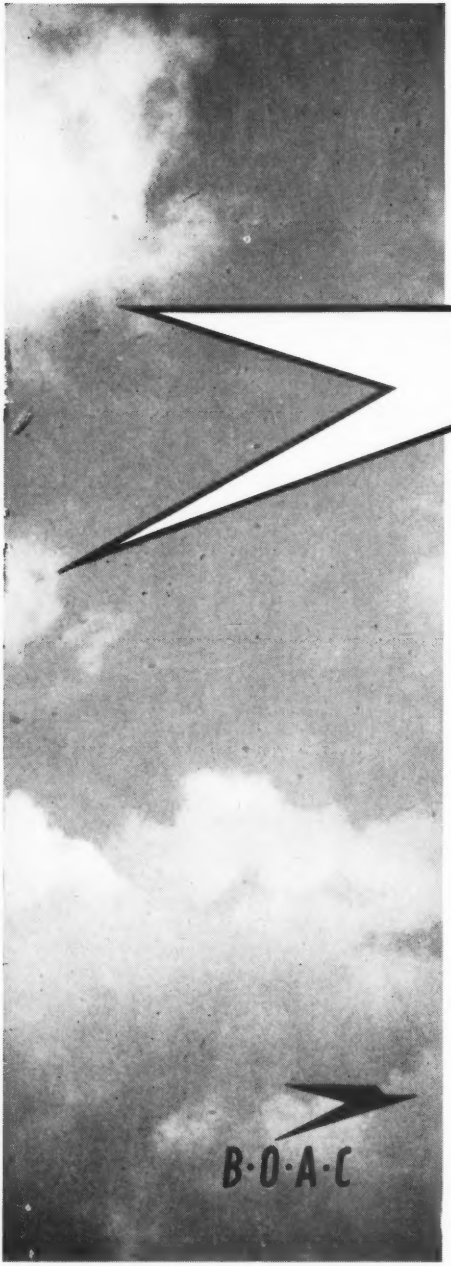

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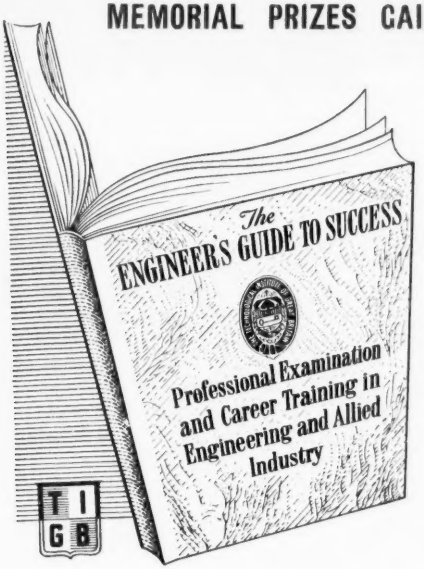

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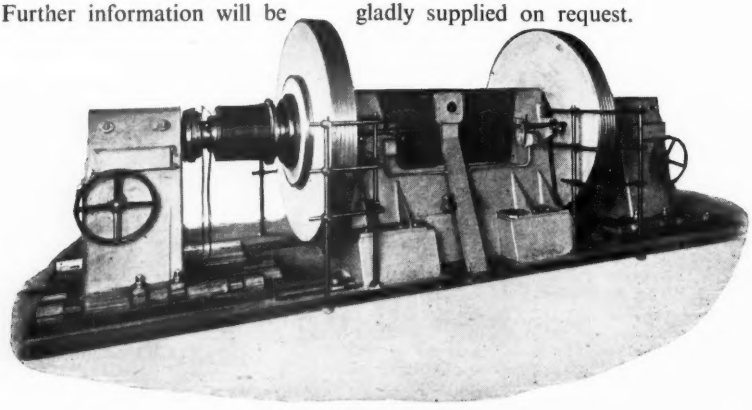

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The 706th Lecture read before the Society—on 19th December 1946 at the Institution of Civil Engineers, Great George Street, London, S.W.1. In the Chair, the President, Sir Frederick Handley Page, C.B.E., F.R.Ae.S.

THE DEVELOPMENT OF THE SPITFIRE AND SEAFIRE

by

J. SMITH, C.B.E., F.R.Ae.S., A.M.I.A.E.

Mr. Smith was apprenticed at the Austin Motor Company and joined their Aircraft Drawing Office in 1919. *In* 1921 *he joined Supermarine as a draughtsman, becoming Chief Draughtsman in* 1926. *He was appointed Chief Designer in* 1938. *He is a Fellow of the Society.*

THE OBJECT of this paper is to discuss the evolution of the wartime fighters the Spitfire and Seafire, designed by the Supermarine Works of Vickers-Armstrongs Ltd. In particular, it will be confined to the design and technical side of the problem. The production undertaking, which resulted in the manufacture of over 22,000 of these aircraft in 33 different types, would undoubtedly need a paper of its own.

In order to make the matter clear it is proposed to begin with a brief history of the early development of high speed aircraft by the firm. The next logical step is to survey the Spitfire family as a whole and to trace the relative importance of the different types, giving some indication of their line of development. Finally, an attempt will be made to analyse the factors which maintained the efficiency of these aircraft at a high level for a period of ten years.

There is one personal matter which the author wishes to point out at once. The subject is one which has occupied his attention almost continuously for the past ten years, and it is not always easy to see such things in their proper perspective. An attempt will be made to present the facts as accurately and dispassionately as is possible for a person so intimately connected with the Spitfire.

Almost the first question to decide in considering the subject of this paper is "What is the major point with regard to Spitfire development?" This seems to the author to be the fact that the Spitfire remained a front-line fighter throughout the whole period of the war. The Spitfire was originally designed by the late R. J. Mitchell in 1935 and first flew in 1936. To-day, eleven years later, a number of Spitfires and Seafires are still on order for the Services. The hard school of war leaves no room for sentimental attachments, and the efficiency of the machine as a fighting weapon is the only criterion. Judging the aircraft on this high standard, the firm's design team took the initiative which resulted in continuous improvement of the type. The table overleaf gives a comparison of the first and last types, and is a measure of what was achieved.

The Spitfire and all connected with it have a major debt to acknowledge. Without the whole-hearted co-operation of another design team, that of Rolls-Royce Ltd., whose magnificent series of engines, the Merlin and Griffon, supplied the power for every Spitfire and Seafire, the development life of the aircraft might have been seriously curtailed. The author wishes to be allowed to offer to Rolls-Royce the grateful thanks of Supermarine for all their efforts on behalf of the Spitfire family.

And now to consider the early development by Supermarine of high-speed aircraft.

At Naples in 1922 the Supermarine Sea Lion, a Napier-engined flying boat, won the Schneider Trophy at a speed of 145.7 m.p.h. In 1923 the Trophy went to America, won by the Curtiss racer biplanes on floats at a speed of 177.4 m.p.h. From then on, the contest changed in character, and became a proving ground for clean aerodynamic shapes and specially hotted-up engines.

By 1925, the late R. J. Mitchell had designed the Napier-engined S.4 monoplane on floats, which established a new World's Speed Record for both landplanes and seaplanes of 226 m.p.h.

A great deal has been written and said about the design and performance of the later S.5 and the two S.6's, notably by the designer himself, and the author will not presume to enlarge upon this. It is sufficient to say that these aircraft enabled Britain to win the Trophy outright in 1931 and to set up a World's Speed Record for seaplanes of 407 m.p.h. It is significant to note that it was at least eleven years before this speed was attained operationally by a fighter aircraft.

There is no doubt that very valuable experience had been gained from the design and manufacture of these racing aeroplanes, and this resulted in a team whose outlook was essentially speed conscious, and who thought in terms of drag reduction by small size, thin wings and aerodynamic cleanliness. A natural outlet for this was its application to a high performance fighter. A design was consequently produced around the requirements of a fighter specification issued by the Air Ministry, based as far as possible on the lines of the Schneider Trophy machines particularly with regard to fuselage and empennage. This machine, the F.7/30, was fitted with a Rolls-Royce Goshawk engine developing 600 h.p. and the wings were of the cranked type, having anhedral inner and

	Spitfire I	*Seafire* 47
Weight, normal	5,820 lb.	10,300 lb.
Weight, overload	—	12,500 lb.
Wing area	242 sq. ft.	244 sq. ft.
Wing loading	24 lb./sq. ft.	42.2 lb./sq. ft.
Maximum horse power	1,050	2,350
Power plant weight	2,020 lb.	3,650 lb.
Maximum speed	362 m.p.h.	452 m.p.h.
Maximum rate of climb	2,500 ft./min.	4,800 ft./min.
Time to 20,000 ft.	9.4 minutes	4.8 minutes
Weight of fire/sec.	4.0 lb.	12.0 lb.
Fuel capacity, internal	85 gallons	154 gallons
Range including allowance for take-off climb and 15 minutes combat	395 miles	405 miles
Maximum range	575 miles	1,475 miles
Rate of roll at 400 m.p.h.	14.0 degrees/sec.	68 degrees/sec.
Permissible C.G. range, percentage mean chord	2.7	11.5
Factored wing loading	240 lb./sq. ft.	464 lb./sq. ft.
Maximum diving speed	450 m.p.h.	500 m.p.h.
Structure weight, per cent.	33.0	31.0
Energy absorption of undercarriage	8,300 ft./lb.	26,600 ft./lb.
Undercarriage stroke	4.9 inches	9.0 inches

Fig. 1.
Comparison between Spitfire Mk. I and Seafire 47.

Fig. 2.
Sea Lion.

dihedral outer portions, with a total area of 295 sq. ft. The cockpit was unenclosed.

While the estimated performance of this machine was achieved, it was felt that a considerable improvement could be made by certain drastic alterations. The experience gained was of the greatest value, and work was begun almost immediately on a further project, a design which ultimately became the Spitfire. The steam-cooled Goshawk engine was retained, but the machine took the form of a low-wing monoplane with greatly reduced wing area and with the pilot's cockpit totally enclosed. (See Fig. 5.)

This design was submitted to the Air Ministry and accepted, with certain modifications. A period of intensive work on this design followed, influenced by three major considerations, the necessity for retracting the undercarriage, the advent of the Rolls-Royce Merlin engine, known originally as the P.V.12, and the Air Ministry requirement for the machine to be fitted with eight machine guns. The advantages to be gained by the first two considerations were obvious, and the wisdom of the third was apparent even in those days, and so these were incorporated in the final design.

At the same time, investigations into various forms of main plane construction revealed advantages to be gained from the use of one main spar at 25 per cent of the

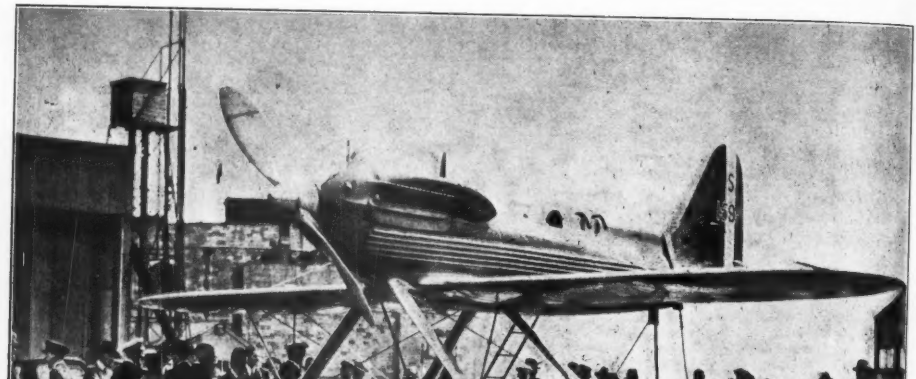


Fig. 3.
The S.6b.

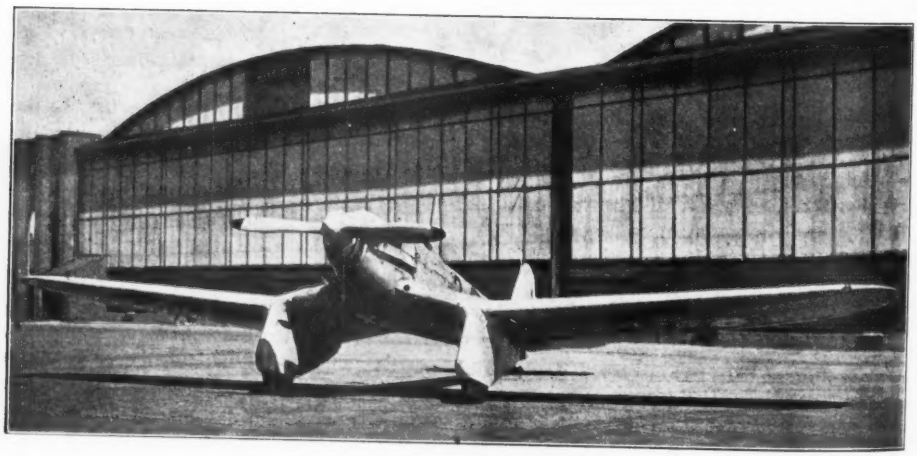


Fig. 4.
The F.7/30.

chord with a torsion box formed by the portion of the wing forward of the spar. The 14-gauge flush riveted covering of this box gave a good form to the most important part of the aerofoil section, and the position of the main spar suited the new arrangement of the chassis and the radiator and gun installation.

The radiator was mounted aft of the main spar, and the ducting arrangement, an innovation, was based on a scheme developed by Meredith of the Royal Aircraft Establishment. It is interesting to note that, apart from spinning tests, the radiator installation was the only part of the original machine tested in the wind tunnel.

The thickness/chord ratio of the wing was cut down to 13 per cent. at the root and 6 per cent. at the tip, the wing area was reduced from 255 to 242 square feet, and the plan form made elliptical. Apart from the engine mounting, stressed skin construction was used throughout, and the structure weight attained of 1,900 lb. was very low indeed. It has, in fact, rarely been improved upon.

With a view to obviating teething troubles, arrangements were made at Duxford for a programme of intensive flying to be done on the first machines in the Service. Some 300 hours flying was completed within an extremely short period, and corrective action taken on a number of defects which came to light.

The Spitfire family has been mentioned, and now follows a brief summary of how that family was developed. During the period 1938-1940 many extensive investigations were made by Supermarine on the problem of fighter development. In this work, many factors had to be considered, and their relative importance and influence on the problem as a whole taken into account. The more important of these were as follows:

Performance. It was obvious that with the country involved in a major war it would be essential to maintain technical

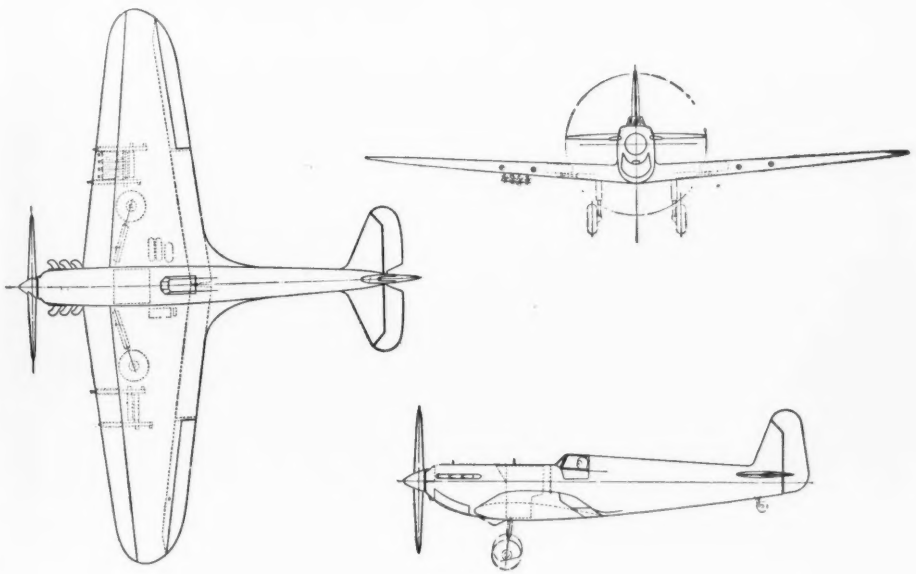


Fig. 5.
Supermarine F.7/30 development Rolls-Royce Goshawk engine

superiority over the enemy in our fighter aircraft.

Armament and equipment. Service requirements were bound to change, and the suitability of the aircraft to take heavier and more cumbersome equipment had to be considered.

Maintenance. Under wartime conditions this aspect was of primary importance, and the possibility of the machine being in use in climates with extremes of heat and cold, and thus needing special equipment, had to be assessed.

Production. For a proper appreciation of this aspect it is necessary to turn one's thoughts back to the situation as it existed during the "expansion" period, and during the early days of the war. From a technical point of view progress would have to be made along the lines mentioned. The preparation of new designs which could never be brought into production in time was obviously useless. New designs were prepared and fully considered in relation to the above factors, but the conclusion reached was that it would be very difficult to improve upon the aerodynamic and structural efficiency of the Spitfire, and that the development of the type was the best course to follow from every point of view. By fitting new and more powerful engines, heavier armament, cleaning up the basic design still further and by periodically strengthening the airframe it was thought that the machine could be kept abreast of requirements.

The main line of development was of course the purely fighter type, but the early introduction of photographic reconnaissance aircraft, and later, the Seafire, gave rise to other separate types. The introduction of the Griffon engine as a replacement for the Merlin made a further main division, and finally, there existed several interim types which bridged the gaps between one mark and the fully developed and strengthened mark which followed. The most outstanding examples of interim types were the Marks IX and XIV.

First, the main line, ignoring the minor changes.

Marks I, II and V were mainly dis-

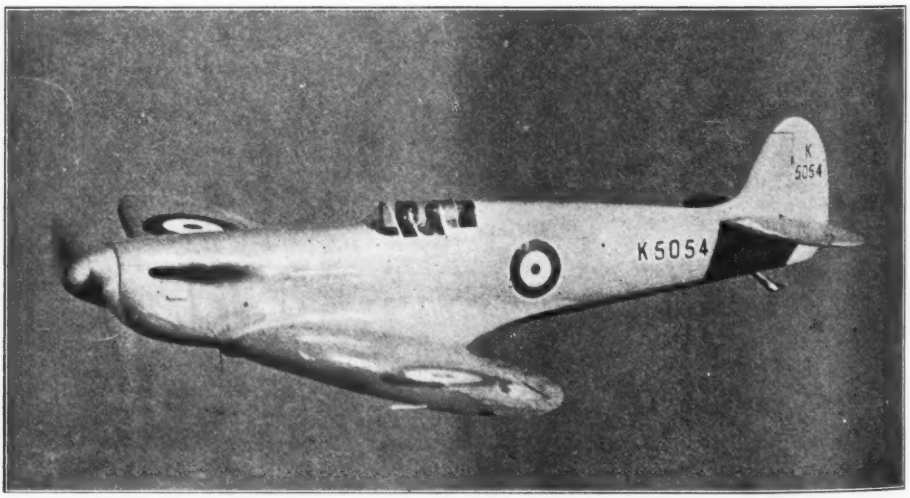


Fig. 6.
Prototype Spitfire.

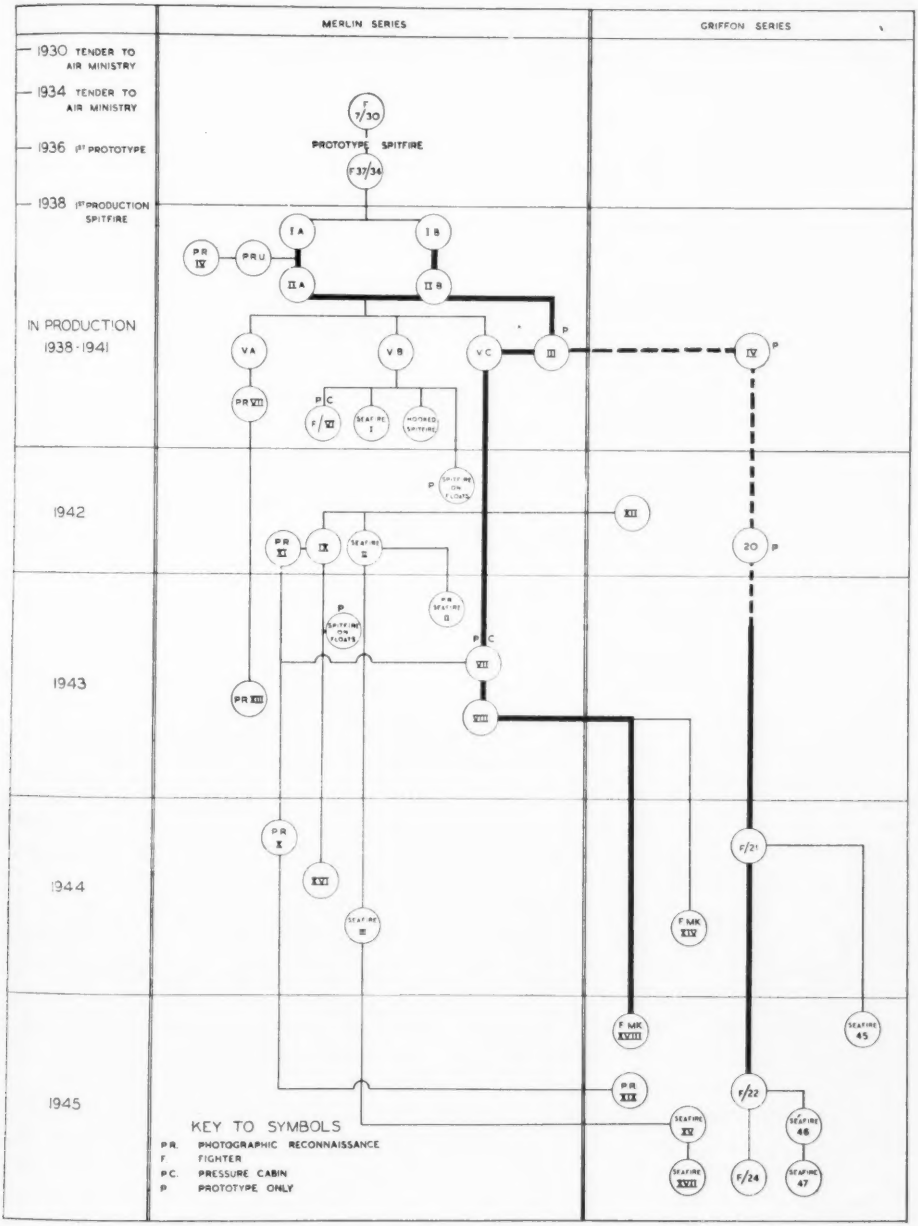


Fig. 7.
The family tree.

tinguished by engine changes with a progressive increase in power and rated altitude of the Merlin. The Mark VI was a development of the Mark V with the addition of a pressure cabin and extended wing tips. Then, in Mark VII, came an extensive redesign which included the fitting of a two-stage Merlin engine, the strengthening of the airframe, the redesign of the cooling system and the incorporation of an improved pressure cabin and a retractable tail wheel. The Mark VIII was an unpressurised version of the Mark VII. Meanwhile, the Merlin 61 engine was fitted to a Mark V machine and the interim type known as the Mark IX was born. This machine had reduced factors, but effectively filled the gap while design work on the Marks VII and VIII was progressing. This completed the main Merlin-engined types.

At a very early stage in the development programme the firm decided to "clean up" the general design of the Service machine. A retractable tail wheel was fitted, the windscreen shape improved, a jettisonable hood added, and a new wing designed to which could be fitted either eight .303″ Browning guns, four Hispano guns or various combinations of both. The wing tips were clipped. This improved machine was fitted with a two-speed blower Merlin XX engine and called the Mark III. Although giving a substantially increased performance the Air Ministry decided against its adoption, possibly on grounds of production, and only two aircraft were built. The design work paved the way for further development, and all the new features embodied in this design were incorporated into later marks.

By this time, advance information from Rolls-Royce on the Griffon engine had been obtained, and design work had begun on the conception of a Spitfire powered by the new engine. A completely redesigned airframe was produced, to be powered by a single-stage Griffon II engine. This machine was known initially as the Mark IV, but was subsequently renamed the Mark XX before the prototype flew in 1942. This work was carried out in parallel with the production of large numbers of Merlin-engined aircraft Marks I to IX, so that when, late in 1942, the necessity arose for a low altitude fighter of high performance, the experience was available, and an interim type using the Mark V airframe and powered by a single-stage Griffon II engine, given clipped wings, a retractable tail wheel and a strengthened fuselage, went into service as the Mark XII.

Meanwhile, the fully developed version was designed with a completely new wing carrying four Hispano guns, a longer undercarriage, a slightly wider track, a larger fin and rudder and fitted with a Griffon 61 two-stage engine. This was the Spitfire Mark 21, a direct descendant of the Marks IV and XX, and represented the highest stage of development of the Spitfire family.

While this new airframe was being put into production Griffon two-stage engines were being flown in Mark VIII airframes to gain experience. The performance obtained with this combination was so satisfactory that it was decided to produce another interim type, which became the Mark XIV. This mark was later fitted with strengthened wings and undercarriage and increased fuel tankage to become the Mark XVIII.

Some further modifications were made to the Mark 21, including a rear vision hood, a completely new empennage and the fitting of a 24-volt electrical system, giving the Mark 22; later, the introduction of rear fuselage tanks to this mark resulted in the Mark 24.

To sum up this main line of development, we have Marks I, II and V as Merlin engine changes, Mark VI as a pressure cabin type, Marks VII and VIII as a redesign, and Mark IX as an interim type between the Marks V and VIII. Using the design experience gained from the Marks III and

XX came the Griffon engined aircraft; first the interim Mark XII and later, using the Mark VIII airframe the Marks XIV and XVIII, followed by the completely re-designed Marks 21, 22 and 24.

The P.R.U. and Seafire branches of the family are more easy to follow, being in most cases specialised versions of existing marks of Spitfire. For further information, the reader is referred to the summarised tables given as an appendix to this paper. The important developments in relation to these types were the integral leading edge fuel tanks and camera installations for photographic reconnaissance machines and the introduction of folding wings, catapult spools and arrester hooks for Seafires.

One further matter remains to be cleared up, namely, the suffix letters which follow the mark numbers in Marks I, II and V. These refer to the armament fitted to the wings. "A" means eight .303" guns, "B" means two 20 mm. Hispano guns plus four .303" machine guns, and "C" means the universal armament wing originally designed for the Mark III.

So much then for the numerous variations on the Spitfire theme which were produced. The next step is to consider the technical aspects of the subject. An endeavour will be made to show how the efficiency of the Spitfire was maintained throughout its life, and it will be convenient to discuss this under the headings of performance, control and stability, fire power and armament, range, structural efficiency, naval problems and special duties.

PERFORMANCE

It is axiomatic that speed is the major consideration in fighter design, coupled with rate of climb, and there is little doubt that the chief reason for the continued success of the Spitfire was the progressive increase in speed, from 362 m.p.h. on the Mark I to 450 m.p.h. on the Mark 24, and its rate of climb from 2,500 to 4,800 feet per minute. So far as climb is concerned, efforts were mainly directed to reducing weight and choosing the right compromise in propeller design and engine gear ratio to suit the next stage of engine development. Extended wing tips in some cases were fitted and by these means the Spitfire's rate of climb was kept ahead of requirements.

It is also a truism to say that speed is a question of combining maximum power with minimum drag. So the policy adopted by the firm of making advance provision for engine development, and at the same time refining and reducing the drag of an already clean aerodynamic shape, paid a handsome dividend.

The increase of power was continuous (see Fig. 9) and the untiring efforts of Rolls-Royce resulted in more than doubling the power of the Spitfire, from a maximum of 1,050 h.p. on the Mark I to 2,350 h.p. on the Seafire 47.

The fact that such an enormous increase of power was accommodated without material alteration in the size of the aircraft, constituted one of the main achievements in the development of the machine and was only accomplished by the closest co-operation between Rolls-Royce and ourselves. It was necessary to redesign in several instances the engine bay forward of the fire-proof bulkhead and in the case of the Griffon engine, the fitting of which to the Spitfire IV was investigated as far back as 1939, it was found at the mock-up stage that several parts of the engine protruded through the side of the fuselage. These parts were redesigned by Rolls-Royce to bring them inside the Spitfire lines.

Increased power necessitated increased cooling, and progressive changes were made to the cooling arrangements in the wing culminating, at the introduction of the two-stage engine, in the use of duplex radiators, one side combining glycol and oil coolers and the other side glycol and intercoolers.

The original air intake was very simple,

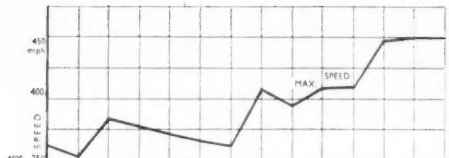


Fig. 8.
Analysis of performance.

with an entry area of 21.5 square inches. It was often referred to as, and in fact was, just a spout. The fitment of snow and ice guards and air filters necessitated a great deal of experimentation to prevent deterioration of intake efficiency and rise in external drag. The entry area on the latest Spitfire and Seafire was increased to 45 square inches, and the simple spout became a complicated component.

The conversion of engine power to thrust was a further problem, and here again, willing co-operation between the airscrew firms and Supermarine produced the desired results. Several alternative designs were prepared, some by ourselves and some by

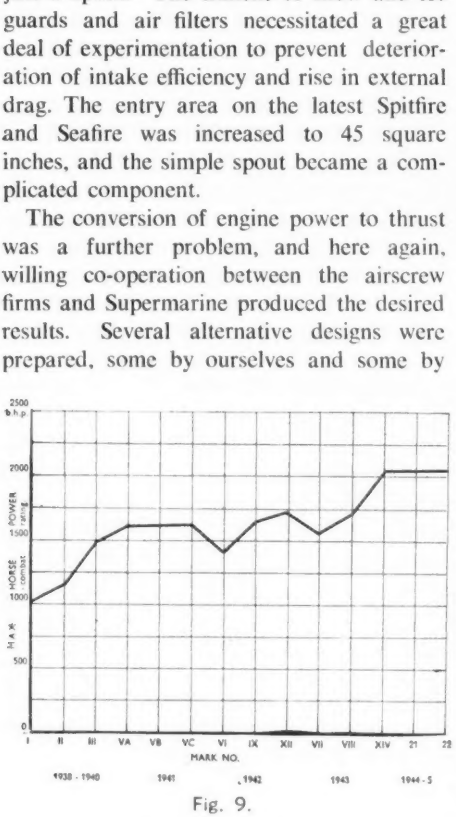


Fig. 9.
Increase in power.

the Airscrew Company of Weybridge, for the original Spitfire, and it was chiefly by airscrew development that the initial speed was increased from 336 to 349½ m.p.h. for the Martlesham prototype trials. The roots of the two-bladed airscrew were fully faired, and modern constant speed airscrews have not all reached such a high standard in this respect.

Soon after production began, the de Havilland three-blade two-pitch airscrew became available, giving valuable improvement in take-off and rate of climb, and these came into service in the Battle of Britain.

At about this time, Supermarine, acting upon a suggestion from Rolls-Royce and

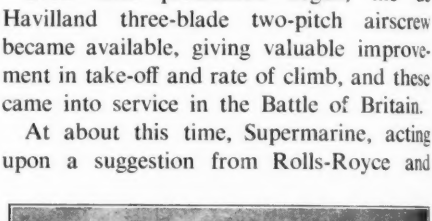


Fig.10.
Griffon engine in mock-up.

using experience gained with fixed pitch airscrews, designed some Jablo blades with faired roots for the Rotol propeller, which gave increased speed.

As the power of the Merlin engine advanced an increase in propeller "solidity" became necessary. With restrictions upon the diameter due to ground clearance, four-bladed airscrews were required, followed by five-bladers for the more powerful Griffon engine. In the meantime, Supermarine were attracted to the idea of a contra-rotating propeller as, theoretically, performance was to be gained and practical experience with torque and gyroscopic effects suggested great advantages in aircraft control due to their elimination. It will be appreciated that this

proposal provided the airscrew and engine manufacturers with a major experimental problem, and the implications, from a production point of view, were extensive. In due course Rolls-Royce produced the gear and Rotols and de Havillands the propellers, and the Spitfire flew with a six-bladed contra-rotating airscrew.

The subject of propeller blade material always remained a vexed question, and it seemed that whenever the propeller manufacturers and ourselves wanted one material, there was invariably an excellent reason why some other material had to be used. Jablo, spruce with Jablo inserts at the roots, hydulignum, magnesium and duralumin were all used as blade material. Altogether thirteen types of propeller have been fitted to the Spitfire, and without the extensive development of this important component the continuous increases in performance could not have been achieved.

Thus the maximum possible power was continuously applied to the Spitfire, and in parallel with this change every effort was made to reduce drag. The prototype aircraft was extremely clean, so that improvement was a matter of detail only, although the incorporation of these improvements involved considerable research work to get them into practical form. Examples are the

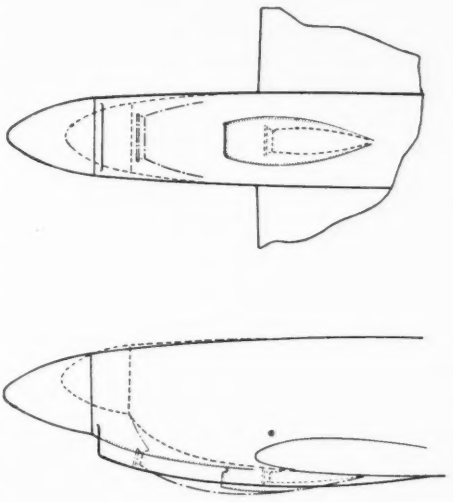


Fig. 11.
Diagram of the various types of air intake used.

retracting of the tail wheel, fairing the roots of the propeller blades, improvements in the shape of the forward fuselage, doors to enclose completely the main wheels, "whip"-type aerial masts, plain ailerons, a curved front windscreen, numerous variations of intake shape, exhaust manifold shapes, and improved surface finish.

To measure the improvement in speed which each of these refinements gave is

Mark No.	*Propeller.*
Prototype and Mark I	Supermarine 2-blade wooden
Mark I, A and B	de Havilland 2-position 3-blade de Havilland 3-blade constant speed
Mark II, A and B	Rotol 3-blade Jablo constant speed
Mark V, A, B and C	Rotol 3-blade magnesium Rotol 3-blade Jablo constant speed de Havilland 3-blade hydromatic
Marks VI, VII, VIII, IX and XII ...	Rotol 4-blade dural Rotol 4-blade Jablo Rotol 4-blade Hydulignum
Marks XIV, 21, 22 and 24	Rotol 5-blade Jablo Rotol 5-blade Hydulignum
Seafire Mark 47	Rotol 6-blade Jablo, contra-rotating.

extremely difficult, but the following figures are a fairly reliable indication of the order of the gains. They certainly confirm that such refinements are far from wasted effort.

Refinement	*Speed increase m.p.h.*
Retractable tail wheel	5
Propeller root fairings	4
Chassis door panel	3
Whip aerial	0.5
Plain ailerons	6
Curved windscreen	6
Multi-ejector exhausts	4
Improved finish and wax polish ...	9
Clipped wing tips	1
Rear view hood and deletion of mirror	1

Fig. 12.
Speed increases due to refinements.

In changing over to the Griffon engine, the opportunity was taken to drop the nose of the aircraft and this gave an improvement to the shape of the forward portion of the machine and slightly improved the pilot's view over the nose. Pilot's view aft had never been considered adequate for operational purposes on the earlier Spitfires, and an external mirror had to be fitted. To meet this criticism, on later marks the aft portion of the fuselage was redesigned and a canopy fitted which was completely external to the fuselage contour.

CONTROL AND STABILITY

The problem of "feel" and ease of control over a wide speed range is not easy of solution, but there is little doubt that the Spitfire set a new high standard in this respect. As development proceeded, and fighting experience became available, determined efforts were made to improve upon it. The aileron control was the first to receive attention. Although very effective at low and moderate speeds, it was found to become heavy and less responsive when, as inevitably happened, pilots dived the machine to its limit during combat. The stick forces and rate of roll were measured, and the results are given in the graphs in Figs. 14 and 15. It will be noted that a change from fabric covering to metal covering for the ailerons effected a marked improvement.

As operational speeds increased still further, the effect of torsional stiffness of the wings on aileron effectiveness became a serious factor, and in designing the wing for the Mark 21 a theoretical reversal speed of 825 m.p.h. was catered for as against 580 m.p.h. with earlier types. An increase in wing stiffness of 47 per cent. was obtained by ensuring rigid load carrying joints at all points of access to the torsion box, and by increasing the gauge of wing plating and modifying the structure at various points on the wing.

Careful analysis over a long period on various marks of Spitfire had revealed fairly wide variations in aileron section and in the position of the ailerons relative to the wings. These differences resulted in inconsistent aileron characteristics, and it was felt that ailerons of a type which would be simple to manufacture and which would be less sensitive to manufacturing tolerances were necessary.

Quantitative data obtained from flight trials on a Spitfire Mark V with plain ailerons fitted with a balance tab had previously indicated that aileron properties comparable with those of a metal-covered

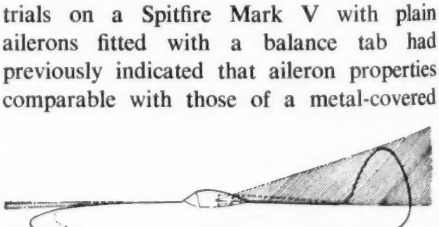


Fig. 13.
Diagram of view angles over the nose and rearward.

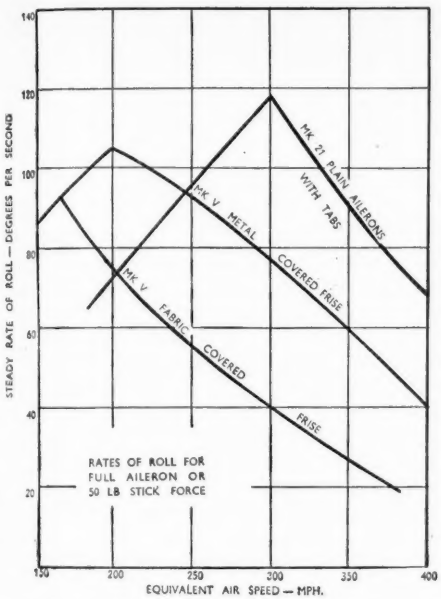


Fig. 14.
Spitfire ailerons. Typical rate of roll curves.

Frise type could be achieved, with a reduction in drag due to the elimination of the gap. Ailerons of this type with area increased to 6 per cent. of the total wing area, as against 5 per cent. on earlier marks, were fitted to the stiffer Mark 21 wing and gave a high rate of roll with reasonable stick forces at high speeds.

The maintenance of a reasonable standard of fore and aft control and stability provided a problem which was continuous throughout the development of the aircraft. On a small fighter such as the Spitfire it is probably true to say that every single modification affected this feature, and the cumulative effect of the alterations on machines in service and on which production was in full swing had to be most carefully considered at all times.

It will be appreciated that under these conditions, remedies for any deterioration in control and stability had to be found which could be applied quickly in the Service and in the factories. Among such remedies were small increases in area of elevator horns, fitment of inertia weights in the elevator control system, slight alterations to elevator section and metal skinning of elevators. Major factors which affected this characteristic were the fitment of heavier and more powerful engines, the use of propellers of higher solidity, increases in fuel capacity and changes in the operational altitude of the aircraft. To cater for these, tailplanes and elevators of increased area had to be used.

One further aspect of this problem that may be mentioned was the effect of expendable load such as fuel and ammunition. The impossibility of positioning all such loads on the aircraft C.G. will be understood, and C.G. movement as high as 9 in. or 11.5 per cent. of the mean chord had to be contended with and steps taken to negative its adverse effect on the handling qualities of the aircraft.

A careful check had also to be kept for any deterioration in directional control and stability of the machine due to modifications, and quick remedies devised to restore this important feature to a reasonable standard. Increases in areas of rudder horns, fitment

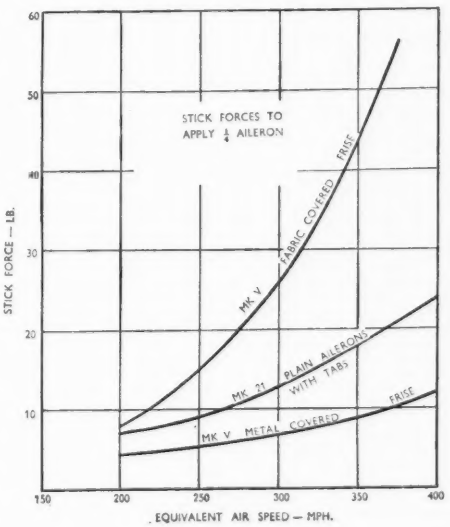


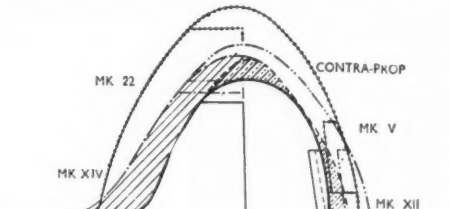
Fig. 15.
Spitfire ailerons.
Typical stick force—speed curves.

of anti-balance tabs, metal skinning of rudders, and rudders of increased area were among the steps tried out and used.

The use of larger and more powerful engines resulted in lengthening the nose of the aircraft and necessitated the use of airscrews of higher solidity. To counteract the destabilising effect of this additional forward finnage substantial increases in the vertical areas aft had to be provided. The various stages in the development of the tail unit are shown in Fig. 16.

FIRE POWER AND ARMAMENT

There can be no doubt that however superior in performance a fighter may be, it is primarily a gun platform, and that the original conception of an eight-gun fighter was sound. Pressure from Fighter Command for improvement in this respect, and also for the introduction of armour to protect pilots during combat, was continuous and every effort was applied to implement the requirements within a minimum time.



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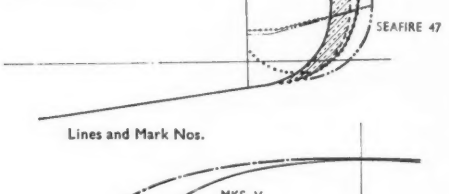


Fig. 16.
Diagram showing relative tailplane and elevator and rudder areas.

The original armament of eight .303" Browning guns, with 300 rounds of ammunition was good for its time, but the need for the greater hitting power of the 20 mm. Hispano gun soon became apparent.

The Spitfire wing layout had to be redesigned to accommodate one of these weapons on each side and four of the .303" Brownings were retained outboard. Arrangements were made on the firing control so that the Browning and Hispano guns could be fired together or separately.

Only 60 rounds of 20 mm. ammunition could be carried, as the drum type magazine was the only one available. This drum also necessitated the fitting of blisters to the wing surfaces. Wings so fitted, that is, carrying four Browning and two Hispano guns, were known as type "b".

Official policy varied considerably as to the best type of armament, and the next step was the production of a wing which could be fitted with either eight machine guns, four machine guns and two Hispanos, or four Hispanos. This was known as the type "c," or universal wing. This universal wing was fitted to Marks Vc, VII, VIII, IX, XII and XIV, and allowed for any variation in policy or the supply of guns. By this time the belt feed was available, allowing ammunition capacity to be increased to 160 rounds per gun.

The next change was the fitting of two .5" Browning guns instead of the four .303" guns, together with two 20 mm. Hispanos on the Marks IX, XIV, XVI and XVIII, giving increased hitting power in the smaller calibre weapon.

Finally, it became evident that 20 mm. ammunition was the only really effective type, and the fitting of four 20 mm. Hispano guns was made standard on Marks 21, 22 and 24, together with the provision of 140 rounds per gun. The bulky blisters stayed to the end in spite of design efforts on the firm's part, and it was not until the Spiteful wing was designed that a satisfactory flat

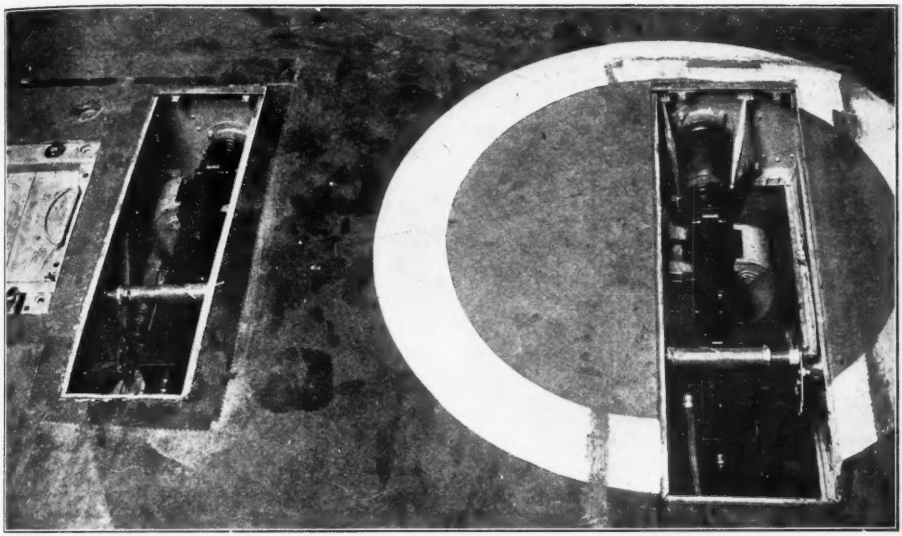


Fig. 17.
.303" gun installation.

feed became available which could be housed within the wing.

To ensure that the guns would operate under extremely low temperatures, often as low as −40°C., a scheme for the heating of the gun compartment in the wings had to be designed. This was achieved by leading warm air ducted from the rear of the radiator duct to the gun bay. An alternative arrangement in which hot air from a heater pipe in the exhaust manifold was ducted down into the wings was also used.

As the use of the machine by the Services was developed, so the need for armour protection of the pilot arose. The first requirement put forward very early in the production of the Mark I was the provision of a bulletproof windscreen, made by fixing externally to the front of the windscreen a 1¼ in. thick bulletproof panel. Some rearward protection for the pilot was the next requirement, also at a very early stage, and 6 mm. plate was introduced behind the pilot's head. Later, 4 mm. plate was added behind the pilot's seat, together with forward protection for the glycol header tank and the top fuel tanks.

As the enemy changed to heavier calibre weapons the density of the armour plate was increased, and the protection extended to other parts of the aircraft. The protection behind the pilot's seat was later increased to two 6 mm. plates with a 6 in. air space between, deflection plates were added under the pilot's seat and on the forward face of the ammunition magazine, and the bullet-proofing of the windscreen extended to the side panels. Light alloy deflector plates were used throughout over the petrol tank bay, and later, in the vicinity of the 20 mm. guns.

The following figures sum up the development in armour and fire power:

	Mk. I	*Mk.* 24
Weight of ammunition	185 lb.	375 lb.
Weight of armour	nil	190 lb.
Weight of guns	195 lb.	580 lb.

RANGE

In considering the range of the Spitfire it must be remembered that the aeroplane was originally designed as an interceptor fighter operating from home bases. Its fuel capacity of 85 gallons only allowed for take-off, a climb to altitude, 1.65 hours cruising and 15 minutes combat at full bore. It has been seen that in the course of development the engine power was doubled, and in the final fighter version of the Spitfire the petrol tank capacity was approximately double that of the original aircraft. The fighting range was actually increased, a feat which required some ingenuity in view of the fact that the size of the aircraft remained virtually constant.

The steps taken may be divided into four stages. First, the expansion to the limit of space of the original main tanks, followed by the introduction of fabric tanks in the leading edges of the wings, the use of subsidiary tanks in the fuselage immediately aft of the pilot's cockpit, and the use of drop tanks.

The expansion of the main tank was confined to the lower tank, and was made possible by the use of welded construction, the material in this case being magnesium.

By taking advantage of every inch of space, and by producing petrol tanks which appeared to have developed a series of carbuncles, the capacity was increased by ten gallons (see Fig. 19). Wing tanks of 36 gallons total capacity were later introduced by fitting strictly tailored Mareng bags into the spaces between the ribs in the leading edge forward of the main spar.

Finally, as far as fixed fuel was concerned, additional tanks were fitted behind the pilot on the later types.

When it became necessary for Spitfires to operate from bases distant from the scene of operations, drop tanks which could be

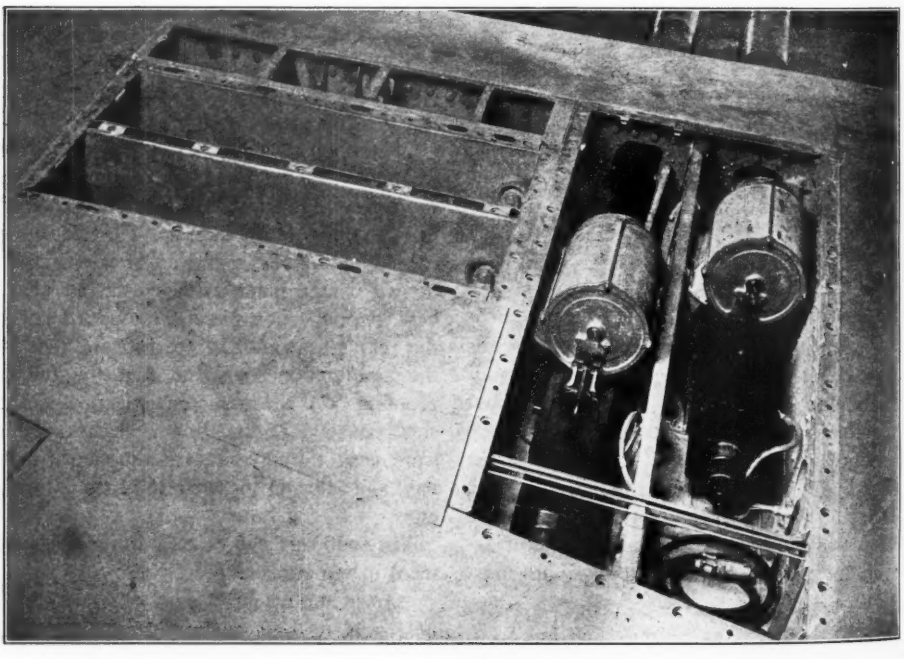


Fig. 18.
20 mm. gun installation.

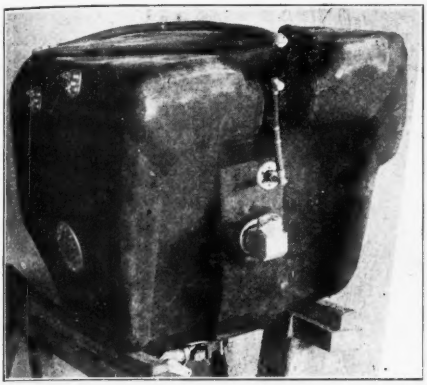


Fig. 19
Magnesium tank.

Fig. 20
Mareng fabric bags in wing.

jettisoned on meeting enemy aircraft, were developed and fitted. A slipper type of tank of 30 gallons capacity was first used (see Fig. 21) and a number of snags were experienced before satisfactory jettisoning was obtained.

In early experiments, this type of tank was found to slide back and hit the tail of the aircraft. In an attempt to throw the tank clear, pivotted arms were fitted to the side of the tank, on the theory that the nose would drop and all would be well. This resulted in the amazing spectacle of the Spitfire flying around with the tank flapping about under the fuselage! The trouble was finally overcome by allowing the released tank to slide back a short distance along the

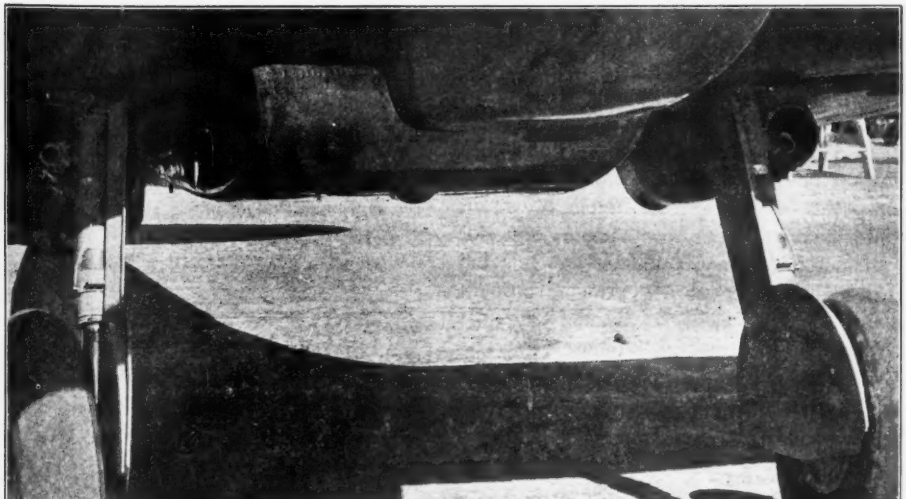


Fig. 21.
30-gallon slipper tank on aircraft.

fuselage until it came in contact with a pair of stops, the nose then dipping and the tank swinging clear.

Various sizes of tanks were produced, including a 90-gallon and a 170-gallon variety. The 90-gallon tank made a very dramatic entry into Spitfire life by enabling these fighters to get through to Malta and play their part in the relief of the Island. They were taken by carrier to within 800 miles of the Island, and then flown off from the deck. The larger tank, while being serviceable, did not improve the appearance of the aircraft, as can be seen in Fig. 23.

It is a matter of interest that during the period of sweeps over occupied France, tens of thousands of 30-gallon tanks were consumed, and that over 300,000 drop tanks for Spitfires were actually manufactured.

In order to reduce drag, later types of drop tank were streamlined in shape, supported by short struts away from the fuselage. They were attached and released by the standard means, and were of 45 and 90 gallons capacity.

The original fuel system was very simple indeed, consisting of two tanks housed in the fuselage between the engine and the pilot, and full interconnection was provided for filling, venting and draining. Thus the tanks could be regarded as one tank. The feed to the engine was by gravity through a single pipe from the sump of the lower tank, and the system was simplicity itself. Unfortunately, this happy state did not remain for long, and problems affecting the fuel system were always present, brought about for the most part by the continual changes in operational conditions.

In a paper such as this it is not possible to go into details of these problems and their remedies, but the following list gives some indication of their extensive nature:

1. Freezing of vents.
2. Vaporisation of fuel under high altitude and tropical conditions.

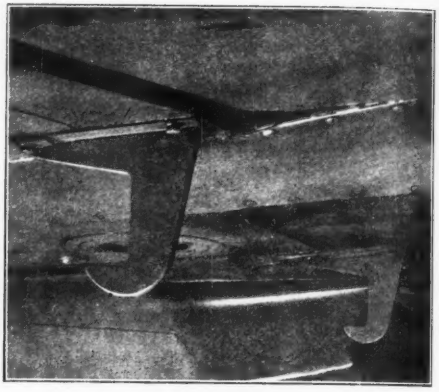


Fig. 22
Stops for slipper tanks.

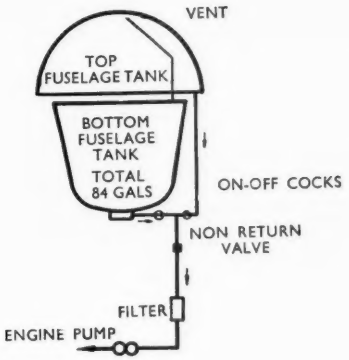
3. Effect of positive and negative acceleration.
4. Oil dilution systems.
5. Engine priming.
6. Bullet-proofing of tanks and system.
7. Transfer, filling and venting arrangements for multiple, including jettisonable tanks.

Figure 24 gives some idea of the development which took place.

Oil was an easier problem, which was solved first by enlarging the original tank

Fig. 23.
170-gallon drop tank.

SPITFIRE MK.I. FUEL SYSTEM



SEAFIRE 47. FUEL SYSTEM

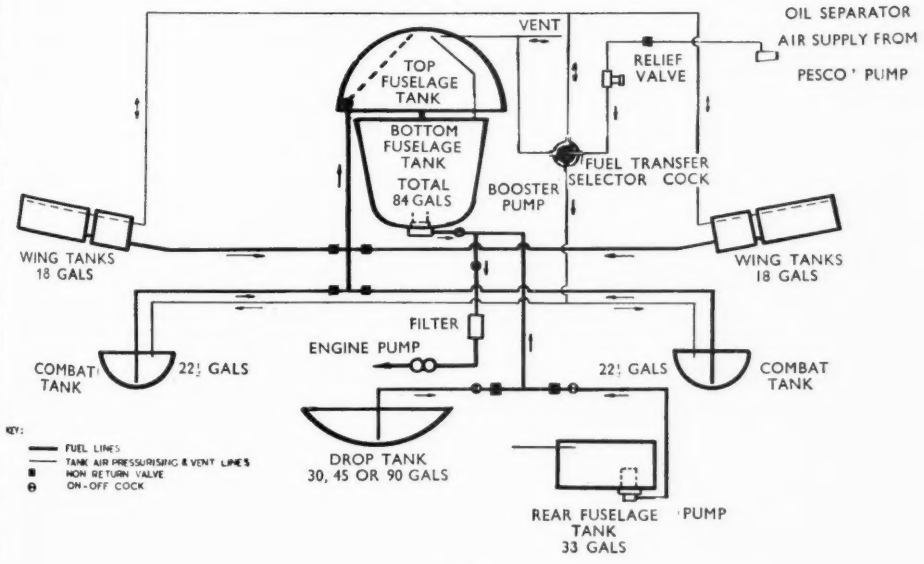


Fig. 24.
Fuel systems of Mk. I and Seafire 47.

under the engine. In the later Griffon-engined types the tank was moved to a position immediately forward of the top fuel tank and aft of the fireproof bulkhead. This new position provided direct gravity feed to the oil pump and also reduced fire risk.

In addition to the above steps taken to increase the range of fighter types, a special long-range P.R. type was developed. The additional fuel capacity was housed literally in the leading edges of the wings. The original structure lent itself very well to this purpose, and with surprisingly little modification was converted into integral tanks of 133 gallons total capacity (Fig. 25).

Fig. 25.
Integral leading-edge tanks.

Sealing strips of synthetic rubber were incorporated at joints, and a special riveting technique was worked out using a liquid sealing compound. Bulkheads with outwardly turned flanges were fitted at each end of the leading edge, and rib baffles to prevent surging during manœuvres were introduced. To each baffle was fitted a non-return valve. Preliminary leakage troubles were experienced and finally overcome by attention to sealing details.

The result was an unarmed aircraft capable of Spitfire speed with a range of well over 2,000 miles and a consumption in propelling 3½ tons through the air of nine miles per gallon.

STRUCTURAL EFFICIENCY

The initial structural efficiency of the Spitfire because of simplicity of design has already been mentioned. Obviously as power and speed increased the loads to be

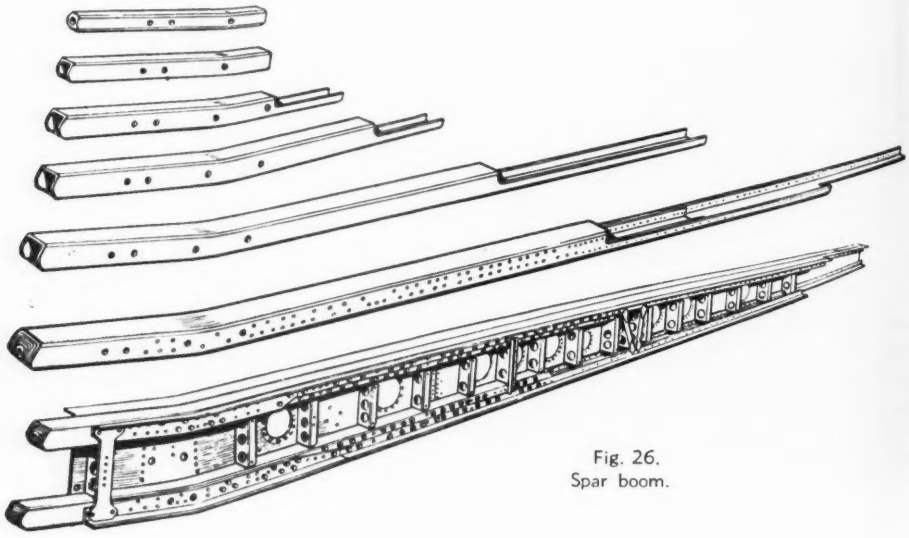


Fig. 26.
Spar boom.

carried became greater, and to maintain low drag any form of external wing reinforcement was ruled out. The resulting problems were solved mainly by the use of materials of higher strength than those originally used, and also by the local application of thicker sections.

The main spar boom (see Fig. 26), which consisted of a series of duralumin tubes telescoped inside each other and stopped off at intervals, lent itself to modification in two ways. First, the relative lengths of tubes were increased, and later, the material of the tubes was changed from T.4 to DTD.273, a higher grade light alloy.

The final development used on the Mark XVIII aircraft was the use of an extruded section in DTD.364 machined on the taper. This was not used on the Mark 21 series because of production considerations.

The stressed skin construction permitted strengthening by increasing the gauge of the skin covering, a procedure which was adopted in various stages on the fuselage in particular.

The introduction of the Griffon engine brought a complete change of engine mounting, from a built-up tubular structure to a semi-cantilever beam type mounting fabricated from light alloy extrusions and sheet.

The final stages required the use of steel longerons in the fuselage and steel reinforcements for the centre section spar booms. The undercarriage was strengthened in stages by thickening the oleo cylinder and the pintle in the wing, and by strengthening the attachment to the main spar.

These structural changes were accommodated without increasing the percentage structure weight, as shown in the curve in Fig. 28.

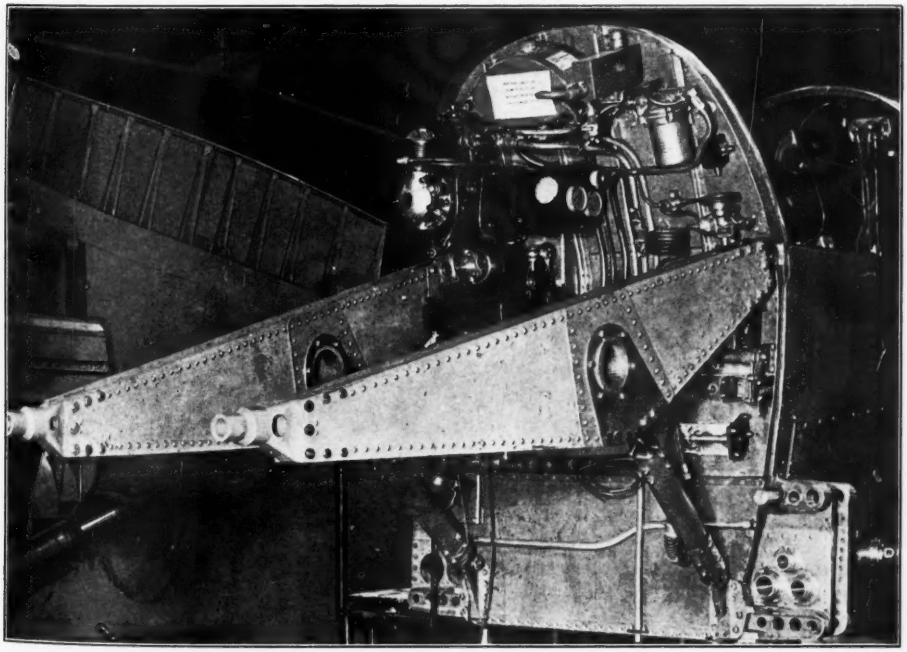


Fig. 27.
Griffon engine mounting.

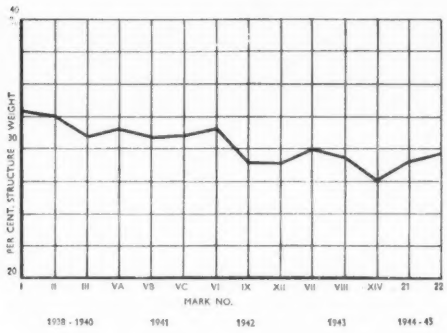


Fig. 28.
Percentage structure weight.

SPECIAL DUTIES

Apart from the Seafire, the development of which will be discussed later, normal Service use called for special jobs. The result was that many of the later marks had three variations: the standard aircraft, known as "F," fitted with a medium altitude rated engine, the "H.F." type, with a high altitude engine and increased wing span, and the "L.F." type, for low altitude work. Three types of wing tip were available, known as standard, extended or clipped, allowing a total variation of wing span of 7 ft. 7 in. or 23 per cent. A still further type of machine known as the "F.R." had a low altitude engine, normal armament and a slightly increased fuel capacity to give greater range. Cameras were also fitted.

The original photographic reconnaissance machine was developed further, as we saw from the family tree (Fig. 7). Various combinations of cameras were installed, and a universal camera installation finally adopted (Fig. 29). Armed versions for low altitude work were also introduced.

As enemy opposition in the air lessened and finally disappeared, the Spitfire was largely used for ground strafing. First bombs, and later, rockets were fitted under the fuselage and wings, and the 20 mm. Hispanos were used to good effect.

In 1941 the threat of high altitude bombing by the enemy had to be faced. No fighter existed in which the average pilot could patrol and fight at 40,000 feet, and the Spitfire took on a new role. It was decided to pressurise the cockpit, and the matter being one of great urgency, the prototype was constructed by the direct modification of a completed Vb aircraft. It was fitted with a special high altitude Merlin 47 engine incorporating a Marshall cabin blower capable of producing 90 cubic feet of air a minute. The wing span was increased by using the extended tips, and a four-bladed Rotol airscrew was fitted.

The major problem was to render the cockpit sufficiently airtight, and this was accomplished by the fitting of bulkheads fore and aft, and a special airtight hood replaced the sliding one. The sealing-off of moving control wires and engine and radiator controls entailed considerable research, the problem finally being solved by the use of special glands and collapsible rubber mouldings (Fig. 30).

Fig. 29.
Spitfire P.R. XIX in flight.

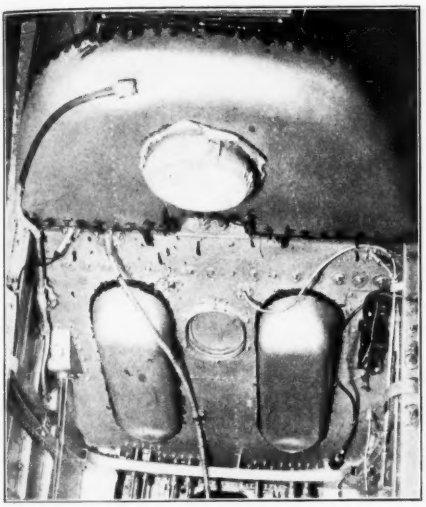


Fig. 30.
Forward bulkhead of Mk. VI.

On the resulting aircraft a cabin pressure of 2 lb./sq. in. was attained, which reduced the apparent altitude from 40,000 to 28,000 feet. The increased span and special engine and propeller resulted in a higher ceiling.

The new Spitfire Mark VII was produced later as a pressure cabin machine, and incorporated many improvements over the earlier type, including a jettisonable type of sliding hood developed by Messrs. Malcolm of Slough.

A great deal of work was put into this branch of development, and although the enemy never used high altitude bombers on a large scale, it was reassuring to know that they could be tackled if they materialised.

During the Norwegian campaign, the firm was asked by the Ministry to consider the conversion of a Spitfire to a seaplane to enable operations to be made from sheltered waters. A Spitfire Mark I was used, and as time was limited a pair of Blackburn Roc floats were fitted. These floats had a reserve buoyancy of 130 per cent. and did not lend themselves at all well to adaptation to the Spitfire. A machine was completed, but because of the early termination of the Norwegian campaign and the urgency of providing aircraft for the Battle of Britain, the machine was reconverted to standard before it flew.

The requirement was not allowed to drop,

Fig. 31.
Seaplane on the water.

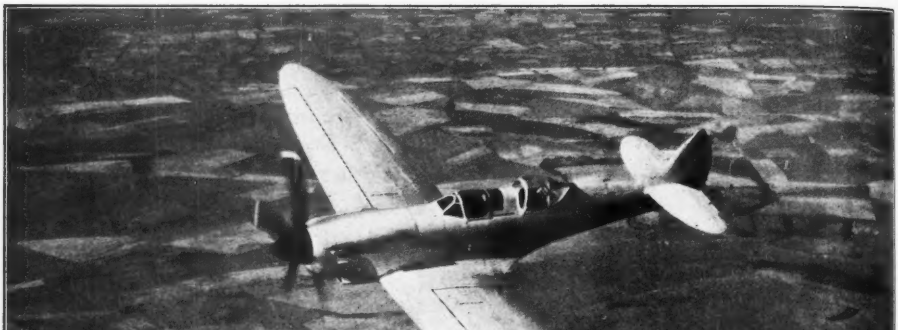


Fig. 32.
Spitfire trainer.

and in 1942 a second float-plane was produced, built around the Mark V. The floats, designed by Supermarine, had a reserve buoyancy of 90 per cent. and were mounted on cantilever struts attached to the mainplane spars at a distance of 5 feet from the centre-line of the aircraft. Additional fin area was fitted under the stern of the fuselage to counteract the destabilising effect of the floats, and the air intake was extended forward to obviate the entry of spray. The handling characteristics of this machine both in the air and on the water were good, and the speed of the standard machine was only reduced by 30 m.p.h.

Subsequently a Mark IX was converted, using the same design of float, and a limited number of these conversions were manufactured (Fig. 31).

More recently a still further conversion of the Spitfire has been made. By moving the existing pilot's cockpit forward it has been possible to build a second cockpit into the fuselage, and by providing a duplicate set of controls a high performance trainer has resulted. The performance of the converted machine remains practically the same as the standard one, and this conversion can be applied to any of the later marks of Spitfire and Seafire (Fig. 32).

NAVAL PROBLEMS

The protection of ships against enemy activity became an acute problem at an early stage, and the need for a naval fighter with the best possible performance became evident. Time did not permit of a new design of naval fighter, so the Spitfire entered on a new phase and took a new name, the Seafire.

Towards the end of 1941 a Spitfire Vb was fitted with an arrester hook in the form of an A-frame hinged to the underside of the rear fuselage. Another machine, this time a Vc, was similarly treated and given in addition catapult spools. A number of both types were built, but their successful operation from carriers raised the much greater problem of wing folding in order to utilise to the full the available hangar space.

The folding of such a thin wing presented apparently insoluble problems if excessive

weight increase and loss of stiffness were to be avoided. Finally, after considering and investigating several schemes it was found possible to introduce two straight fore and aft folds. The wing was hinged and arranged to lift vertically from a point near the root but outboard of the radiator, and a second fold, situated at the wing tip joint, turned downwards (Fig. 33).

The increase in weight was only 125 lb., and the decrease in torsional rigidity when tested found to be 10 per cent. This was considered to be satisfactory, and the folded width of the aircraft was 13 ft. 6 in. as against the normal span of 36 ft. 10½ in. The prototype aircraft was a directly modified Vc, and was known as the Seafire III.

With the introduction of the Griffon engine the Seafire XV was produced (Fig. 34).

Deck landing characteristics were improved by fitting a new form of arrester hook known as the sting hook. With the original form of arrester hook fitted under the rear portion of the fuselage a fairly large moment about the C.G. of the aircraft was produced, resulting in a nose-down pitching of the machine on engaging the arrester wires of the carrier. The new sting hook cut down the moment and considerably improved the deck-landing characteristics of the machine (Fig. 35).

On a later version of the Seafire, the Mark XVII, a rear vision hood was incorporated and also an undercarriage giving greatly improved shock-absorbing characteristics. Another feature brought in on this type was the curved front for the pilot's windscreen, achieved by fixing a curved plate glass panel in front of the bulletproof screen.

Fig. 33.
Seafire III with wings folded.

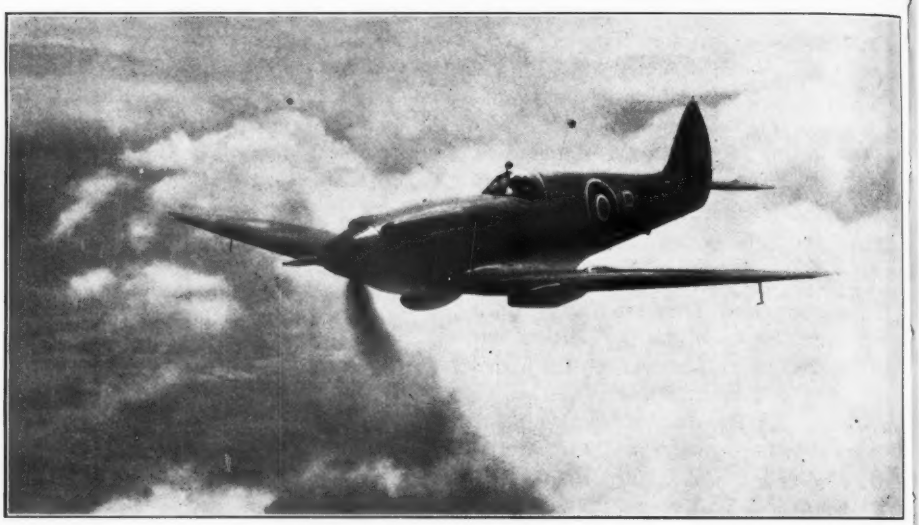


Fig. 34.
Seafire XV in flight.

Flight trials indicated speed gains as high as 7 m.p.h. at 400 m.p.h. with this type of faired screen, and the sandwich effect caused by the additional front panel served a useful purpose in preventing misting up of the bulletproof screen (Fig. 36).

Conversions of the latest type of Spitfires are now being produced for the Royal Navy. The basic type used is the Mark 21 series, and the latest naval versions incorporate such features as contra-rotating propellers, increased flap areas and long stroke undercarriages.

CONCLUSIONS

In summarising the factors which allowed the solution of the technical development problems facing the firm over a period of ten very busy years, several general impressions emerge. Firstly, the Spitfire was superbly served by its power plant, and full advantage was taken of the alliance of a new airframe with engines which were only at the start of their development life. Also, the close co-operation between Rolls-Royce, the airscrew firms and ourselves, enabled advance provision to be made for engine changes.

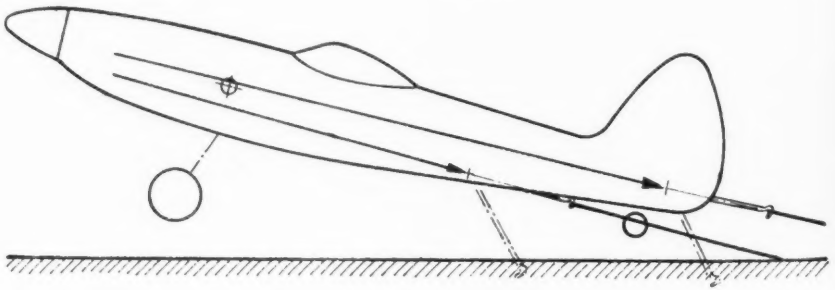


Fig. 35.
Action of A-frame and sting arrester hooks.

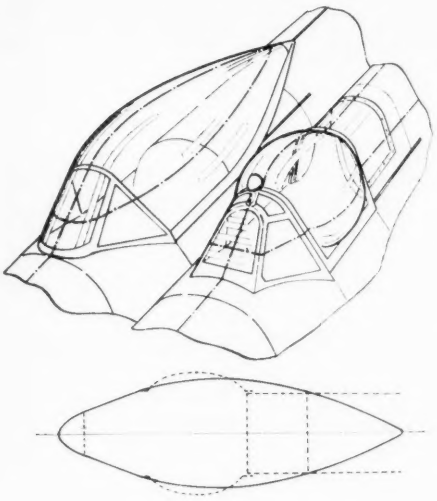


Fig. 36.
Comparison of standard and rear view hoods.

Secondly, the sound basic design of the aircraft with its outstanding simplicity enabled major modifications to be incorporated without materially altering the original conception. Although very few details remained unaltered by the time Mark 24 was built, the layout and design principles on which the aircraft was based persisted throughout. During the two major redesigns, those of the Mark VIII and the Mark 21, careful consideration was given to suggested fundamental changes, but the advantages to be gained were too nebulous to warrant departure from the tried and proved Spitfire layout.

Thirdly, the continuous improvement in aerodynamic cleanliness, the maintenance of ease of control and structural efficiency were in the hands of a design team working continuously over a period of ten years on the improvement of a type which they had originated. Finally, the co-operation received from officials and officers of the Ministries and Services concerned was at all times whole-hearted and extremely helpful, and without it, no progress could have been made.

It is hoped that the few glimpses given of the problems tackled and their methods of solution will have helped to increase the generally held affection for the Spitfire, with which the author and his colleagues are so proud to have been associated.

Fig. 37.
Seafire 47 on the ground.

Mark	Engine	Engine mounting	Propeller	Engine cowling
Ia and Ib	Merlin II or III	Tubular	2-position de Havilland 3-blade 2-blade fixed pitch or 3-blade de Havilland constant speed	Sectional, quick release fasteners
II	Merlin XII	Tubular	3-blade Jablo Rotol constant speed	No change
III	Merlin XX	Tubular, extended Mk. I	3-blade Jablo Rotol constant speed	No change
Va and Vb	Merlin 45 series	As Mk. I	3-blade Rotol constant speed or 3-blade de Havilland, bracket or hydromatic type	No change
Vc and tropical	Merlin 45 series	As Mk. I	No further change	No change
VI	Merlin 47 series	As Mk. I	4-blade Jablo Rotol	No change
VII	Merlin 61 series	Tubular, extended	Rotol 4-blade Hydulignum	Extended to suit and louvred for Marshall blower
VIII	Merlin 61 series	No further change	No further change	Extended to suit
IX	Merlin 61 series	No further change	No further change	No further change
XII	Griffon III or IV	Built-up box members	4-blade Jablo Rotol	Blistered over cylinders
XIV	Griffon 65	As Mk. XII extended	5-blade Rotol	Amal type fasteners
XVI	Merlin 266	Tubular, extended. As Mk. IX	4-blade Rotol	Extended, as Mk. IX
XVIII	Griffon 65	Extended, Mk. XII	5-blade Rotol	Amal type fasteners
21	Griffon 61 or 64	Built-up box members, as Mk. XVIII	5-blade Rotol	No further change
22	Griffon 61 or 64	No further change	No further change	No further change
24	Griffon 61 or 64	No further change	No further change	No further change

INSTALLATION

Air intake	Exhaust manifold	Radiator type and frontal area	Intercoolant radiator	Oil cooler and area
Temperate	Triple ejector plain or fish tail ends	Serck, 1.88 sq. ft. or Morris QA, 1.85 sq. ft.	Nil	Serck, 0.2 sq. ft.
No change	No change	No change	Nil	Serck, 0.35 sq. ft.
No change	No change	Serck WS, 6450 1.45 sq. ft.	Nil	Serck, 0.35 sq. ft.
Temperate or tropical	No change	Morris QCV, 1.88 sq. ft. or Morris QCY, 2.04 sq. ft.	Nil	No further change
Temperate or tropical	No change	No change	Nil	No change
Temperate	No change	Morris QCV, 1.88 sq. ft.	Nil	No further change
Temperate	Multi-ejector	Two Morris QCP, each 1.24 sq. ft.	Morris QCR 0.72 sq. ft.	Morris QCQ 0.6 sq. ft.
Tropical	No further change	No further change	No further change	No further change
Temperate or tropical	No further change	No further change	No further change	No further change
Temperate	No further change	Morris QCY, 2.04 sq. ft.	Nil	Serck, 0.35 sq. ft.
Tropical	No further change	Morris QFG and QFJ each 2.45 sq. ft.	Morris QFH 2.45 sq. ft.	Morris QFK 2.45 sq. ft.
Temperate or tropical	No further change	Two Morris QCP each 1.24 sq. ft.	Morris QCR 0.72 sq. ft.	Morris QCP 0.6 sq. ft.
Tropical	No further change	Morris QFG and QFJ each 2.45 sq. ft.	Morris QFH 2.45 sq. ft.	Morris QFK 2.45 sq. ft.
Tropical	No further change	Morris QEW and QEY each 2.45 sq. ft.	Morris QEV 2.45 sq. ft.	Morris QEZ 2.4 sq. ft.
Tropical	No further change	Morris QGD and QGE each 2.45 sq. ft.	Morris QGC 2.45 sq. ft.	Morris QGF 2.45 sq. ft.
Tropical	No further change	As above	As above	As above

ENGINE

Mark	Engine	Engine mounting	Propeller	Engine cowling
Seafire I	Merlin 45 50 55 46 50A or 56	Tubular	3-blade constant speed Rotol or 3-blade de Havilland, bracket or hydromatic type	Sectional, quick release fasteners
Seafire II	Merlin 32 45 or 46	No change	4-blade Rotol	No change
Seafire III	Merlin 45 50 55 46 50A or 56	No change	4-blade Rotol	No change
Seafire XV	Griffon VI	Built-up semi cantilever beam	4-blade Rotol	No change
Seafire XVII	Griffon VI	As Seafire XV	4-blade Rotol	No change
Seafire 45	Griffon 61	As Seafire XV	5-blade Rotol	Extended, with Amal type fasteners
Seafire 46	Griffon 87	As Seafire XV	2-3 blade Rotol contra-rotating	As above
Seafire 47	Griffon 87	As Seafire XV	2-3 blade Rotol contra-rotating	As above
PR. IV	Merlin 45 46 50 55A 55 or 56	Tubular	3-blade de Havilland constant speed	Sectional, quick release fasteners
PR. VII	Merlin 45 or 46	No change	No change	No change
PR. X	Merlin 64	Extended, tubular	4-blade Rotol constant speed	Extended to suit engine
PR. XI	Merlin 61 63 63A or 70	Extended, tubular	4-blade Rotol hydulignum	Extended to suit engine
PR. XIII	Merlin 32	Tubular	3-blade de Havilland	As PR. VII
PR. XIX	Griffon 65 or 66	Built-up semi cantilever beam	5-blade Rotol constant speed	Extended, with Amal type fasteners

INSTALLATION

Air Intake	Exhaust manifold	Radiator type and frontal area	Intercoolant radiator	Oil cooler and area
Temperate or tropical	Triple ejector, plain or fish-tail ends	Morris QCY, 2.04 sq. ft.	Nil	Serck, 0.347 sq. ft. S.799-3C-528R
No change	No change	No change	Nil	No change
No change	No change	No change	Nil	No change
Tropical	Multi-ejector	Morris QCP, 1.24 sq. ft. Morris QCV, 1.85 sq. ft.	Nil	Morris QCQ 0.6 sq. ft.
Tropical	No further change	No further change	Nil	No further change
Tropical	No further change	Morris QGD and QGE each 2.45 sq. ft.	Morris QGC 2.45 sq. ft.	Morris QGF 2.45 sq. ft.
Tropical	No further change	No further change	No change	No further change
Tropical	No further change	No further change	No change	No further change
Temperate or tropical	Triple ejector	Morris QCY 2.04 sq. ft.	Nil	Serck, 0.347 sq. ft. S.799-3C-525R
Temperate	No change	Morris QCV 1.85 sq. ft.	Nil	No change
Tropical	Multi-ejectors	2 Morris QCP each 1.20 sq. ft.	Morris QCR 0.714 sq. ft.	Morris QCQ 0.6 sq. ft.
Temperate or tropical	No further change	No further change	No change	Morris QCR 0.6 sq. ft.
Temperate	Triple ejector	Morris QCV 1.85 sq. ft.	Nil	Serck, 0.347 sq. ft. S.799-3C-525R
Tropical	Multi-ejector	Morris QFJ and QFG each 2.46 sq. ft.	Morris QFH 2.46 sq. ft.	Morris QFK 2.46 sq. ft.

WINGS

Mark	Wings Span	Wings Area, sq. ft.	Wing tips	Armour lb.	Armament
I, A and B	36′ 10″	242	Standard	—	Mk. IA—8 Brownings Mk. IB—4 Brownings 2 Hispanos
II, A and B	36′ 10″	242	Standard	73	As above
III	30′ 6″ 36′ 10″	220 242	Clipped Standard	88 88	8 Brownings 4 Brownings and 2 Hispanos, or 8 Brownings, or 4 Hispanos
VA VB	36′ 10″	242	Standard	129 152	8 Brownings 2 Hispanos and 4 Brownings
VC	36′ 10″	242	Standard	193	Universal
VI	40′ 2″	248½	Extended	152	2 Hispanos and 4 Brownings
VII	40′ 2″	248½	Extended	202	2 Hispanos and 4 Brownings
VIII	36′ 10″ or 40′ 2″	242 or 248½	Standard	202	2 Hispanos and 4 Brownings, or 4 Hispanos
IX	36′ 10″	242	Standard	202	2 Hispanos and 4 Brownings
XII	32′ 7″	231	Clipped	180	2 Hispanos and 4 Brownings
XIV	36′ 10″ or 32′ 7″	242 or 231	Standard or Clipped	180	2 Hispanos and 4 Brownings
XVI	36′ 10″	242	Standard	202	2 Hispanos and 2 0.5″ Brownings
XVIII	36′ 10″ or 32′ 7″	242 or 231	Standard or Clipped	180	2 Hispanos and 2 0.5″ Brownings
21	36′ 11″	244	Special Mk. 21 type	190	4 Hispanos
22	36′ 11″	244	Special Mk. 21 type	190	4 Hispanos
24	36′ 10″	244	Special Mk. 21 type	190	4 Hispanos

WINGS

Mark	Wings Span	Wings Area sq. ft.	Wing tips	Armour lb.	Armament
Seafire I	36′ 10″	242	Standard	161	2 Hispanos and 4 Brownings
Seafire II	36′ 10″	242	Standard	202	2 Hispanos and 4 Brownings
Seafire III	36′ 10″	242	Standard shape, folding	202	2 Hispanos and 4 Brownings
Seafire XV	36′ 10″	242	As Mk. III	180	2 Hispanos and 4 Brownings
Seafire XVII	36′ 10″	242	As Mk. III	164	2 Hispanos and 4 Brownings
Seafire 45	36′ 11″	244	Special Mk. 21. Non-folding	190	4 20mm. Hispanos
Seafire 46	36′ 11″	244	As Mk. 45	190	4 20mm. Hispanos
Seafire 47	36′ 11″	244	As Mk. 45, folding	190	4 20mm. Hispanos
PR. IV	36′ 10″	242	Standard	85	Nil
PR. VII	36′ 10″	242	Standard	129	8 Browning guns
PR. X	36′ 10″	242	Standard	85	Nil
PR. XI	36′ 10″	242	Standard	85	Nil
PR. XIII	36′ 10″	242	Standard	152	4 Browning guns
PR. XIX	36′ 10″	242	Standard	85	Nil

FUSELAGE AND UNDERCARRIAGE

Mark	Fuselage	Windscreen	Tailwheel	Undercarriage
I	Light alloy monocoque	External bullet-proof screen or plain perspex	Fixed	Outwardly retractable oleo unit
II	No change	No change	No change	No change
III	Strengthened	Internal bullet-proof screen	Retractable	Strengthened, and wheel moved 2 in. forward
V, A and B	As Mk. I with reinforced longerons	No further change	Fixed	As for Mk. I
VC	No further change	No further change	Fixed	As for Mk. III
VI	Pressurised cabin. Bulkheads fore and aft of cabin	Special non-sliding hood	Fixed	As for Mk. VC
VII	Basically as Mk. VI Strengthened to take increased engine loads	Double-glaze, sliding	Retractable	As for Mk. VC
VIII	Strengthened	As Mk. V	Retractable	As for Mk. VC
IX	As Mk. V, strengthened	As Mk. V	Fixed	As for Mk. VC
XII	Mk. V strengthened, with special attachments at Fr. 5 for Griffon engine	No further change	Fixed, later retractable	As for Mk. VC
XIV	Mk. VIII strengthened, special attachments for Griffon engine	No further change	Retractable	As for Mk. VC
XVI	As Mk. V	As Mk. V	Fixed	As for Mk. VC
XVIII	Mk. VIII still further strengthened	As Mk. XIV	Retractable	As Mk. V, strengthened
21	Redesigned to suit increased loads	No further change	Retractable	Strengthened and extended. Fairing flaps fitted
22	As Mk. 21	Rear vision hood	Retractable	As Mk. 21
24	As Mk. 21	Rear vision hood	Retractable	As Mk. 21

FUSELAGE AND UNDERCARRIAGE

Mark	Fuselage	Windscreen	Tailwheel	Undercarriage
Seafire I	Light alloy monocoque. Arrester hook and slinging points	Internal bullet proof	Fixed	Outwardly retractable oleo unit
Seafire II	As Mk. I with reinforced longerons. Arrester hooks, slinging points and catapult spools	No change	Fixed	Strengthened
Seafire III	As Seafire II	No change	Fixed	As Seafire II
Seafire XV	As Seafire II, strengthened. Later a/c had sting hooks	No change	Retractable	As Seafire II
Seafire XVII	As Seafire XV with sting hook and accelerator hooks	Rear view hood and curved screen	Retractable	As Seafire XV with long stroke oleo legs
Seafire 45	As Spitfire Mk. 21 with sting hook	As Seafire XV	Retractable	As Spitfire Mk. 21
Seafire 46	As Spitfire Mk. 22 with sting hook	As Spitfire Mk. 22. Rear view hood with flat screen	Retractable	As Seafire 45
Seafire 47	As Mk. 46. Accelerator hooks	Rear view hood with curved screen	Retractable	Strengthened and with long stroke oleos

FUSELAGE AND UNDERCARRIAGE

Mark	Fuselage	Cameras	Windscreen	Tailwheel	Undercarriage
PR. IV	Light alloy monocoque with camera installation	2 vertical F.24 1 oblique F.24	Plain perspex	Fixed	Outwardly retractable oleo unit
PR. VII	No change	2 vertical F.24 1 oblique F.24	Internal bullet-proof	Fixed	No change
PR. X	Pressure cabin	Universal	As Spitfire Mk. VII(F)	Retractable	No change
PR. XI	Special PR type for universal camera installation	Universal	Plain perspex	Fixed, later retractable	No change
PR. XIII	As Mk. I with reinforced longerons	2 vertical F.24 1 oblique F.24	Internal bullet-proof	Fixed	No change
PR. XIX	Pressure cabin	Universal	As Spitfire Mk. VII(F)	Retractable	No change

CONTROLS

Mark	Ailerons	Rudders	Elevators
I	Frise type fabric covered	Horn balanced type, fabric covered	Light alloy construction, fabric covered
II	No change	No change	No change
III	No change	No change	No change
VA and B	Later a/c had metal covering	No change	No change
VC	No further change	No change	No change on early aircraft. Later types had extended horn
VI	No further change	No change	As Mk. I
VII	Reduced span	Large chord of increased area	Extended horn balance
VIII	Reduced span	No further change	No further change
IX	As Mk. VC	No further change	No further change. Metal covered on later aircraft
XII	As Mk. VC	No further change	As Mk. I
XIV	As Mk. VIII	Increased area, fin and rudder	Extended horn balance
XVI	As Mk. VC	As Mk. VII	Extended horn balance, metal covered
XVIII	As Mk. VIII	Increased area, fin and rudder	Extended horn balance
21	Plain, balanced tab. Extended span	No further change	Extended horn balance with rounded horn
22	As Mk. 21	Further increase in area of fin and rudder	Increased area of tailplane and elevator
24	As Mk. 21	As Mk. 22	As Mk. 22

CONTROLS

Mark	Ailerons	Rudders	Elevators
Seafire I	Frise type, metal covered	Horn balanced type, fabric covered	Light alloy construction, metal covered
Seafire II	No change	No change	Later aircraft had extended horn. Metal covered
Seafire III	No change	No change	No further change
Seafire XV	No change	Large chord rudder as Spitfire Mk. XII	No further change
Seafire XVII	No change	No change	No further change
Seafire 45	Plain ailerons with geared tabs	Horn balanced type, fabric covered. Increased area as Spitfire Mk. XIV(F)	Metal covered with rounded extended horn
Seafire 46	As Seafire 45	Fabric covered, increased area as Spitfire Mk. 22(F) Horn balanced with anti-balance trimmer tab	Increased area. Metal covered
Seafire 47	As Seafire 45	As Seafire 46	As Seafire 46
PR. IV	Frise type, metal covered	Horn balanced type, fabric covered	Light alloy construction fabric covered. Extended horn
PR. VII	No change	No change	No change
PR. X	No change	Increased area as Spitfire Mk. XII(F)	No change
PR. XI	No change	No further change	No change
PR. XIII	No change	As PR. IV	No change
PR. XIX	Reduced span	Horn balanced type, fabric covered. Increased area as Spitfire Mk. XIV	No change

DISCUSSION

Mr. A. G. Elliott (Rolls-Royce Ltd., Fellow): Rolls-Royce Ltd. were in the happy position of being associated with the Spitfire development, and it seemed to have been the right policy to concentrate on a good basic design and then to go forward, increasing its performance in every possible way. The Merlin engine originally had a nominal power of 900 h.p., but it was developed eventually to give 2,450 h.p., at which power it had passed the official tests for Service use.

He did not profess to know much about aircraft, but he had always regarded the Spitfire dimensions as being the minimum practicable for a fighter aircraft in which a pilot could fight and fly with reasonable comfort. The dimensions of some of the German machines which were brought down in England at that period, however, were about 10 per cent. smaller than those of the Spitfire, and their weight was 1,000 lb. less. An attempt had been made to put a Merlin engine into one of those German aircraft. The engine would go in quite easily and they had wanted to fly the machine fitted with that engine for information, but somehow or other the project was dropped.

His reason for commenting on the size of the Spitfire was that they could have packed in front of the bulkhead much more power than was used even ultimately with the Griffon engine. The Griffon was placed in front of that bulkhead and, as shown by the picture of the mock-up, they had put the cowling around it and everything went in nicely; it gave a better shape of nose than the Merlin version. They could have installed a still larger engine than the Griffon as it was then fitted but the dimensions of the machine were settled by reference to the requirements of the pilot and the functions to be performed by the aircraft, rather than by the engine.

However, there were still further developments ahead. Incidentally, with the improved fuels available, the boost on the engine could have been increased beyond the figure ultimately used. They had reached 25 lb. and even 30 lb. boost, and had actually run an engine at 45 lb. boost, using the very high octane fuels.

Mr. N. E. Rowe (British European Airways, Fellow): He had been impressed by the emphasis Mr. Smith placed on development as a thing in itself, and the light which the paper had shed on how that could best be done in proper conditions. The basis clearly put down in the paper was to start with something which was basically first-class in the way of design, coupled with a power plant which had great development potential; then, given a team which were convinced of its potentialities and were full of enthusiasm, they could proceed to develop that combination to great lengths.

He felt certain that no one who was connected with the Spitfire in its early life would have prophesied that the powers, the weight and the performance, as set out in the paper, would have been achieved at the present stage. In a way it was a classic example of development in all its aspects because, as always, development involved a great deal of research.

Possibly there was much confusion of thought on such matters from time to time. There were some who spoke of development and research as being unrelated, or as representing rather different orders of things; but from the story of the development of the Spitfire and Seafire they could see clearly how closely development and research had proceeded together. For instance, the aileron problem in connection with the Spitfire had given work for research workers in the Company and in the national Establishments for many months, and it had yielded to the combination of research and development applied in the best co-operative sense.

Another great achievement, completely *ad hoc*, was the changing of the aircraft into a pressure-cabin machine. He remembered

well the tremendous struggle involved, and the result was quite a triumph in its way.

Another condition, which had resulted in the development of the aircraft proceeding so extremely well, was the team spirit and the sense of co-operation in reaching the final objective which had existed between the engine and the aircraft sides, and which had had the happiest results. Without that, he felt quite sure, they would not have achieved the great results obtained.

The paper included some interesting figures concerning the effect of small details on the drag of a clean aircraft such as the Spitfire. Those figures made significant and convincing reading for those engaged in design, on the importance of such details.

Some rapid mental calculations he had tried to make had not afforded him any conclusive idea of how far the final performance of the aircraft was due to aerodynamic and engine improvements respectively. At one time there had been some gentle banter to the effect that the Spitfire development was due to engine development; but he believed Mr. Smith would say that there had been a good deal of improvement aerodynamically as well.

The clipping of the wing had apparently given little result; much smaller, he imagined, than would have been expected, having regard to the amount of area removed. Perhaps Mr. Smith would comment on that.

The main lesson was in the essential genius of their people for development, *i.e.*, getting the most out of something by a steady process, by the work of enthusiasts.

Dr. H. Roxbee Cox (Vice-President, Fellow): Mr. Smith was his oldest friend in aeronautics for it was something like 27 years since they were junior draughtsmen together in the aeroplane department of the Austin Motor Company. It seemed remarkable that in all that time Mr. Smith had not previously presented a paper to the Society; he hoped that his reappearance before the Society would not be delayed as long.

One of the most impressive features of the Spitfire was the consistency of its form, as mentioned by Mr. Smith. Apparently it had not been necessary to change the original conception. He remembered it well in the early days, about 1935, when he and Mr. Meredith had visited Mr. Mitchell at Southampton; the drawings then had looked much as the machine looked to-day. They were far more optimistic then about what the machine would do than was Mr. Mitchell, who was extremely modest about its possible achievements; those achievements must have been a source of great delight to him.

A most interesting feature of the machine was the structural form of the wings. There were earlier examples in this country of the "D" spar form, but one of the first to be widely used was in the Spitfire. In any case, that was an outstanding example of its use. Its advantages were made manifest by the Spitfire, and it was a little surprising that they had not seen a great deal more of this method of construction, particularly as it permitted a favourable disposition of the wing axes of importance in flutter and divergence prevention.

Mr. F. Radcliffe (Handley Page Ltd., Fellow): He had for long been interested in fighter development and would have liked one or two more tables included in the author's excellent paper, particularly with reference to the aerodynamical features of the aircraft, giving, for instance, particulars of the drag at, say, 100 ft. per second in the Mark I design and in the aeroplane in its latest form. He made that suggestion because the paper had a great deal of historical value, and in the future they would all be interested to see how much had been done on what would then be regarded as a relatively "dirty" aeroplane.

He would like Mr. Smith's comments on the straight tapered wing, which he believed was used on the Spiteful, as compared with the wing of the Spitfire; and whether, from the aspect of increased production, the use of the elliptical wing would be justified to-day.

He asked for information on the sizes of wheels and the tyre pressures used throughout the history of that interesting series of aeroplanes. Originally the wheels were small enough; but with the increase of weight from 5,800 lb. to 12,500 lb., and apparently with the same size of wheels, the tyre pressure and the strength of the tyres must have increased very considerably.

Air Commodore T. G. Pike (D.O.R.): The Spitfire had been used extensively for fighter-bombing, and it had carried various forms of bombs regularly and frequently, principally the 500 lb. bomb. He believed it could have carried more; but unfortunately it could not carry the 1,000 lb. bomb because of the problem of ground clearance.

From time to time the Spitfire had carried various other loads. On at least two occasions to his knowledge it had taken off with an unwilling passenger on the tail; but it had landed quite safely.

He also recalled that during the Normandy invasion a particularly popular modification was introduced known as Mod. XXX. This enabled a barrel of beer to be carried under each wing at a time when supplies were short in France.

Mr. P. G. Masefield (Director-General, Long-Range Planning and Projects, Ministry of Civil Aviation, Fellow): Mr. Smith had been rather modest about the historic importance of the Spitfire: he believed that, when the history of the first two hundred years of Aviation came to be written, the Spitfire would be found to be one of the immortal aeroplanes. He recalled the influence of the Schneider Trophy races on aircraft design, as well as on the Merlin engine.

He believed Mr. Smith could have said something more about the reasons why the different parts of the Spitfire were formed as they were. For instance, he believed there were some interesting debates in the early stages of the design concerning the form of the undercarriage, and he believed Mr. Smith could have been quite interesting on the reasons why the wheels retracted outwards and not inwards. There was also the prominent off-set radiator, which he believed was the result of the original idea of cooling by steam.

Mr. R. G. Worcester (*The Aeroplane*): Why was the Seafire 47 not fitted with power-folding wings?

Mr. E. Norman-Wilson: He would like some information concerning a large bulge which was seen in 1941 under the port wing of certain Spitfires, about half way along the span.

The President: The paper was an extraordinarily interesting historical document, showing in the successive stages the various improvements which were effected in the aircraft and the different engines which were fitted. But they would also like to know, in addition to the good things that were done, what were the bad things that were found out during the development of the aircraft. He did not make that remark to detract from the excellence of the aircraft design or the engine design; but everybody engaged in the development of aircraft knew that there was a thing called the centre of gravity, which would move backwards or forwards to some unfortunate or inconvenient point, whatever was tried to prevent it so doing. Would it be possible, in an annexe to the paper, to recount a few of the difficulties and disappointments that were experienced, and to indicate how they were overcome? It was from those that future designers would learn much. In the course of the development of the Spitfire there must have been many occasions on which things had gone entirely wrong, and an account of what had happened on some of those occasions would give much useful information.

In the first section of the paper the author referred to the F.7/30, and the President quoted the statement that: "While the estimated performance of this machine was achieved, it was felt that a considerable improvement could be made by certain

drastic alterations. The experience gained was of the greatest value, and work was begun almost immediately on a further project. . . . " What was the "considerable improvement" which it was felt could be made, and what were the "drastic alterations"? The wing had an anhedral in the centre: were difficulties experienced due to body-wing interference?

The S.6 was fitted with a Rolls-Royce engine which had developed 2,500 h.p., and the speed attained was 407 m.p.h. In the Spitfire as ultimately developed, a speed of, say, 400 m.p.h. was attained with a good deal less h.p. The S.6 was a seaplane, and had the disadvantage of the resistance offered by the external floats; such floats no longer formed part of the drag element of the Spitfire, which had a retractable undercarriage. He would like to know the gradations of drag reduction that came with the successive developments of the aeroplane; he would like to see—if he might be allowed to say so without disrespect—a technical annexe to the paper explaining in considerable detail, and the more detail the better, the value of each different arrangement and alteration that was made.

The illustrations in the paper showed that there were successive cuts in both the elevator and the rudder. Such experience was reminiscent of the troubles that had occurred in the development of other aircraft; for example, the shape of a rudder would be altered and it would be supposed that the new shape would give marvellous results, but when it was tried in the air it would prove to be worse than the previous shape. The same remarks applied to elevators. Could Mr. Smith give the various hinge moments and the main turning moments and elevator moments resulting from the various changes that were made; could he indicate the reasons for making the various changes and how the machine had behaved after the alterations were made?

It would be interesting if, to Fig. 16, the diagram showing relative tailplane and elevator and rudder areas, some precise technical details could be added to show what had happened as the result of the changes made, because in the future, when they looked back at the development of what would then be regarded as a very "dirty" aeroplane, as Mr. Radcliffe had suggested, they would appreciate what extremely efficient use had been made of the limited knowledge and experience at the disposal of the designer. If in the year 1946 an aeroplane which was designed about the year 1935 was considered they were amazed by the crude way in which those responsible had proceeded in the earlier year, and they appreciated how much time might have been saved, not so much in the big things, but in the little parts which went to make up the design. The greater the amount of technical information which could be added to the statistics given in the paper to make the account of the Spitfire complete, the better.

Again, in addition to the picture which Mr. Smith had given of the development of the Spitfire, it would be of great interest to have a similar picture or pictures of the Hurricane, the Typhoon and the Tempest. With great respect to the Spitfire, he believed that in the Battle of Britain a great many more Hurricanes than Spitfires were engaged; they would like to know what were the drag elements in the Hurricane, and how the successive improvements were effected.

The paper showed clearly the value of research and development, how a design could gradually be stretched more and more and great improvements effected thereby; if the basic design were right, a wide field lay open for development.

Many people seemed to think that the next step forward would be an enormous leap, But things did not happen that way in the world; neither the human beings which comprised the world, nor their mental capacities, moved forward in great leaps. The world was stodgy and solid, and it possessed an enormous "moment of inertia" in every direction, so that generally progress was slow.

If at any time there were an enormous leap, they found that the world had suddenly gone on a switchback, and that there followed an enormous crash. The application of engineering knowledge and engineering science and principles to their everyday life, and the making of them easily understandable and usable by the general public, could be effected only by development through a succession of failures.

Thus there was a great deal to be said for development work in that field, and for the research which went with it; in that kind of work the Royal Aeronautical Society, by free discussion, provided a useful forum for all to take part and to learn more about aircraft and their design. He hoped that in the future there would always be as free as possible an interchange of technical information, so that the greatest amount of technical detail would be properly presented before the Society and properly digested. There was no art which required so much exposition of its technique as did that of aeronautics.

Dr. Roxbee Cox had referred to the "D" spar; he believed that that was first employed by Messerschmitt in one of his machines; indeed, he had had a patent for it. He would not like to claim too much precedence for particular machines in this country, but he recalled that the Hampden had had a "D" spar in its design in the year 1932-33, having been built to a specification issued by the Air Ministry known as B.9/32. This, too, was an aircraft which had experienced a great deal of stretching in its development. It had started life with a total weight not exceeding 9,000 lb., being fitted with a Bristol Mercury engine, and having to conform to some extraordinary disarmament proposal which was then rife; but it had grown in strength and weight, as had the infant Samuel, and ultimately it had reached an all-up weight of some 24,000 lb. The Spitfire was not the first machine to which the "D" spar was applied.

Dr. Roxbee Cox: He had merely suggested that the Spitfire was one of the earliest applications, and that there were probably earlier applications.

The President: It would be of advantage to add to the paper a short bibliography of the technical memoranda and reports which had been issued by the R.A.E. and other organisations concerning the Spitfire. If the reference to the various documents could be grouped under headings relative to the structure, aerodynamics, controls, and so forth, they would form a useful compendium, so that, not only would they appreciate the tremendous amount of work that had been done, but they would also be able to learn a tremendous amount from the developments which had been effected.

MR. SMITH'S REPLY

Mr. Elliott: He believed that the Messerschmitt 101 was slightly smaller than the Spitfire. Had the Spitfire been a little smaller than it was, it would probably have suffered at a later stage because he did not think the larger engines could have been put into the fuselage. In any case he did not think that a much larger engine could have been fitted to the Spitfire, as Mr. Elliott had suggested, except by having some of it inside and some outside! You could not get a quart into a pint pot. But his Company were always willing to try, and he felt sure that had their appetites been whetted by the offer of an engine of 5,000 h.p. they would probably have succeeded in getting it in somehow.

It was particularly interesting to hear Mr. Elliott say that a lot of extra power could still be looked forward to from the Griffon engine. He was quite sure that the extra power could be used, and his Company would probably get into touch with Mr. Elliott in regard to this matter at a later date.

Mr. Rowe: Development had proceeded from what was considered to be a good basic design, as an alternative to throwing it aside

and starting afresh from time to time. That was particularly important in wartime. He could not help feeling that, had other tactics been adopted, the country as a whole might have lost something, although perhaps he was a little biased in this respect. It was not claimed that anything particularly clever had been done, except perhaps in sticking to the Spitfire design and getting out of it the last ounce. Nobody had asked that it should be made to fly backwards, but had such a request been made, the firm would have tried!

On the question of aerodynamic refinement as distinct from engine power, he drew attention to the list given in the paper. Something like 40 miles per hour was added to the speed of the aircraft by a series of small improvements. Although these improvements appeared to be small, they had involved quite a lot of research work. For example, on the prototype Spitfire, the tail skid was sticking out, but obviously it had to be put inside. That was done, but it was not easy, because everything was very tight dimensionally. Again, experiments on the clipping of the wing were started at a very early stage, and the speed was increased by three or four miles per hour thereby. But this modification had also given a very much improved rate of roll, which was the main feature. This was particularly important during the war, when the Germans could turn away more quickly than the British machines in a high speed dive, so that they could not follow them.

Dr. Roxbee Cox: Many years ago they had designed together what they thought were very good aeroplanes: but nobody had appreciated them.

The "D" spar of the Spitfire had given a fine finish to the leading edge of the main plane, and that had stood the aeroplane in good stead as the speed increased.

Mr. Radcliffe: The point raised concerning particulars of drag could be coupled with the suggestions made by the President, and it would be of value to have a list of all the technical information given in reports on the Spitfire. Such an addition would make the paper a lengthy volume and the work of preparing it would occupy some time; but he agreed that it was worth while doing in respect of the Spitfire and other famous types, and would make for ease of reference. He would endeavour to make a start in that direction.

Mr. Radcliffe had referred to the straight tapered wing as compared with the elliptical wing. The manufacturing point of view was the main consideration. The elliptical wing had been found to be difficult to make accurately, In the case of the Spiteful a wing was required which was accurate to within a few "thou," and unless it could be made easy to manufacture, it could not be hoped to achieve the dregree of accuracy required in production. Wartime experience showed that only in the case of "one off," made by hand, could the difficulties be overcome.

That raised an important point. Wing finish was now a matter of great importance, and he foresaw a difficult problem ahead in that respect. Probably a wing could be designed which would meet the aerodynamic requirements and one or two could be built accurately, but he felt that it would not be easy to build a hundred or a thousand with sufficient accuracy to be able to avoid running into trouble.

The strength of tyres had been increased enormously. Close co-operation had been maintained with the wheel makers, and stronger covers had been produced. At one stage it had been necessary to adopt the split type of rim to enable the tyre manufacturers to produce tyres having much stronger walls. The tyre manufacturers had also used improved materials.

Air Commodore Pike: The later marks of the Spitfire could carry three 500 lb. bombs. In view of the fact that the Spitfire had been known to take-off and land with a man sitting on the tail, the contention could hardly be made that the machine would not carry an extra 30 gallons of fuel behind the pilot.

The modification XXX covered rather an amusing item of Spitfire history. After D-Day it was found that there was apparently a shortage of beer on the other side. It was suggested to certain pilots that they could take supplies over in their jettisonable tanks. This was tried but was not entirely successful as the tanks affected the taste of the beer. The seriousness of this situation was realised and an 18-gallon beer barrel was measured and suitable crutches made up for carrying the barrel on the bomb racks of the machine. In order to camouflage the work involved, it was put through under the modification title "Spitfire XXX Depth Charge."

Mr. Masefield: He could not agree more concerning the value of Schneider Trophy races. In the development of the Spitfire, the work which had been done during the period of the Schneider Trophy tests had proved of great value. It was difficult to assess the exact value of such work; but most of those who had been concerned with racing aircraft were conscious of the importance of drag reduction. The immediate reaction of such people to projections outside the lines of fuselage or wings was to delete them. Such a reaction was the right one in designing high speed aircraft, and its applications would become more and more important in the future. He suggested that it would be a good thing if someone would put up another trophy and start another competition. He was not certain what the datum should be, but suggested something like 850 miles per hour.

One of the reasons why the wheels of the Spitfire retracted outwards was to enable the undercarriage load to be got farther inboard and so reduce the loads on the main spar.

Mr. R. G. Worcester: There had been a demand to produce the Seafire 47 very quickly. Work was also being done on the Spiteful and on the naval version, the Seafang, and in the Seafang, power folding of the wings had been concentrated upon and actually achieved. He agreed that power folding was a necessity, and hoped that it would be achieved even yet on the Seafire 47.

Mr. Norman-Wilson: Some trials had been made with a large fuel tank placed about half way along the wing. It was the first type of additional fuel tank designed and fitted to the Spitfire, and it was not continued. It fitted closely around the leading edge of the main plane, but it was not jettisonable, and it was required to change over to a tank which could be dropped. It was felt that if an attempt was made to drop a tank from that position, trouble would be experienced by way of damage to ailerons, and therefore they reverted to the fuselage position.

The President: He agreed that quite a lot of difficulties had been experienced in the development of the Spitfire, and there was no desire to hide them. The wheel problem was one of those difficulties, and if time had been available, probably a larger wheel would have been tried. But the space in the wing in which to put the wheel was limited, so that an increase in size would have meant a major modification. Therefore the only course to take was to badger the wheel makers continually to produce a stronger wheel: the wheel makers were exceptionally good, and had worked hard to produce what was required.

It would be difficult to go through all the bad features in connection with the development of the Spitfire. There had been quite a lot of trouble with regard to C.G. movement: it could not be hoped to put all the equipment on the aircraft's C.G. and such equipment could only move towards the tail. In this particular case it was a serious matter, because to some extent there was no alternative. It could not just be decided to put on a 30 per cent. increase of tail unit without seriously dislocating production, a factor which had to be taken into account very seriously in those days. If, however, as the President had suggested, a volume could be produced giving references to all the technical information concerning the Spitfire, and

possibly a résumé of some of the troubles experienced, the remedies adopted and the reasons for their adoption, it would be extremely useful. The information existed, and the problem was to collate it and put it together in one volume.

He was glad that he and his colleagues had not claimed to introduce the "D"-shaped spar: had they done so, they would probably have been shot down in flames!

He endorsed the President's remarks concerning the value of discussions; if there were more of them giving the people interested the opportunity for real off-the-record talks, much good would result. They should be an off-the-record free-for-all.

Aircraft design and construction were really a complex form of engineering, and chief designers had to rely more than ever on the advice and information given by their staffs. He had been particularly fortunate in that he had always had the benefit of a loyal and able staff to help him.

THE ROYAL AERONAUTICAL SOCIETY

The 707th Lecture read before the Society—on the 30th January 1947 at the Institution of Civil Engineers, Great George Street, London, S.W.1. In the Chair, the President, Sir Frederick Handley Page, C.B.E., F.R.Ae.S.

DEVELOPMENT OF AIR TRANSPORT DURING THE WAR

by

AIR MARSHAL THE HON. SIR RALPH COCHRANE K.B.E., C.B., A.F.C.

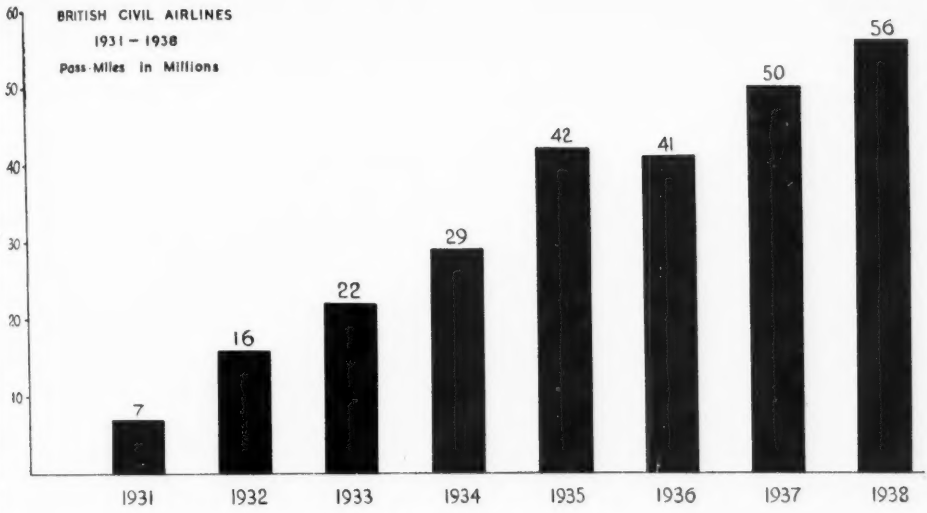
Air Marshal Cochrane entered the Royal Navy in 1912 *and served during the* 1914-18 *War with the R.N.A.S. In* 1919 *he transferred to the R.A.F. and between the wars served with distinction in the Middle East and in various posts at home. From* 1940 *until* 1942 *he was Director of Flying Training and then served for the rest of the war with Bomber Command, first as Air Officer Commanding No.* 3 *Group and then as A.O.C. No.* 5 *Group. He was appointed Air Officer Commanding in Chief, Transport Command in February* 1945.

THE heading of this lecture is the "Development of Air Transport During the War" but because time is limited I have had to exclude any mention of the ferry organisation which was responsible for the delivery by air of many thousands of aircraft. The work has however been described in "The Atlantic Bridge." The period with which I propose to deal is the 21 months ending in September, 1946. In this short period, in response to the demands of war, the Transport services of the Royal Air Force flew rather more passenger miles than did British Civil Aviation in the preceding 21 years up to the same date, and carried in addition great quantities of freight and military stores. This volume of transport flying, packed into a few short months, gave rise to many problems but also afforded unique opportunities for testing out new ideas and new equipment. My purpose tonight is to give a brief account of what was accomplished, and against this background to examine some of the lessons which were learned and the ideas for the future to which they gave rise.

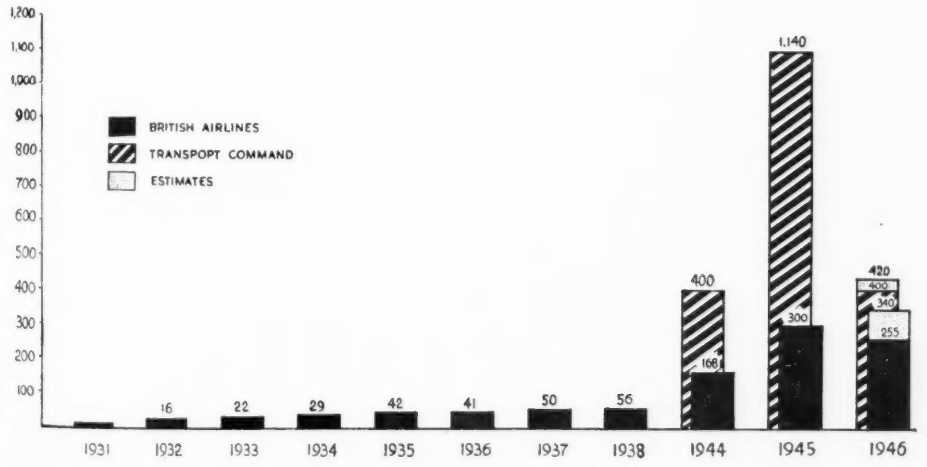
Many of the problems to be solved were inherent in the rate at which the Command grew in an effort to meet a military situation which was dependent to an increasing and unexpected extent upon the use of air transport. This rate of growth, which has such an important bearing on the problems of organisation, administration and training, is perhaps better illustrated graphically.

Figure 1 shows the steady upward trend of pre-war British airlines from a capacity of 7 million passenger miles in 1931 to 56 million in 1938. Fig. 2 shows the same figures alongside those of the war. The 56 million is now dwarfed by the 400 million of 1944 and the 1,100 million of 1945, and the pre-war rate of expansion, so steep in the early diagram, is hardly noticeable.

Figure 3 shows in greater detail the monthly Transport Command figures for 1945, subdivided among the various categories of flying. At the bottom of the pillars are shown the scheduled services which performed tasks akin to those of pre-war British airlines, with the exception that their routes lay in all parts of the world from the Atlantic to the Pacific, across Europe, Africa and Asia into China, and to many other parts of the



AIR TRANSPORT DEVELOPMENT
Pre-War Perspective
Fig. 1.



AIR TRANSPORT DEVELOPMENT
Passenger Miles in Millions
Fig. 2.

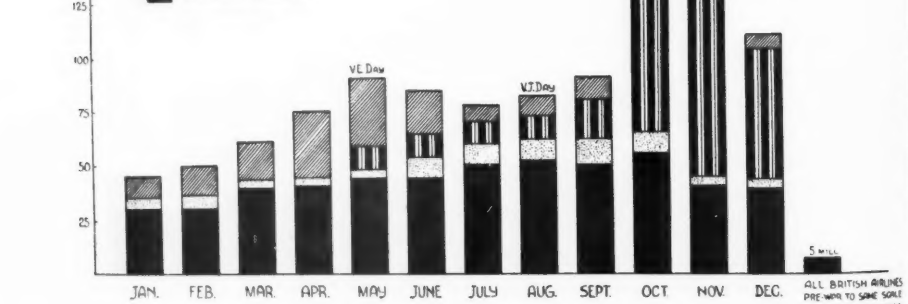
world where facilities were either primitive or non-existent. The extent of the routes along which regular scheduled services were being run is shown in the map.

Above the scheduled services in Fig. 3 comes a section of the pillar representing special flights, equivalent in civil air transport to "charter services." A considerable number of aircraft were always held ready to leave at short notice for any part of the world. The nature of their duties and the urgency of the missions on which they were sent often involved special hazards because of inadequate navigation aids and, in many parts of the world, lack of meteorological information.

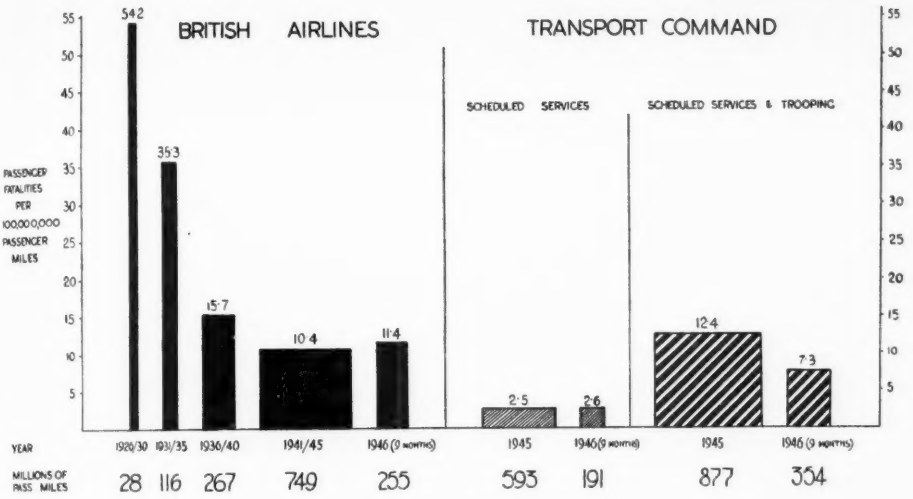
Next to the special flights is shown trooping, designed originally for the transfer of forces from Europe to the Far East, but reversed after the fall of Japan to bring home troops due for release. At the October peak the Command was running what virtually amounted to an hourly service to India, and moving 10,000 troops a month in each direction. Because of the scale of the operation and the short time available for preparation, the task involved many special problems, not least in organisation and administration along the route. Nevertheless it was small in comparison with the achievements of our opposite numbers — the U.S.A.T.C. — who, over the same period, were moving 50,000 troops a month across the Atlantic.

The top section of the diagram refers to transport operations in support of the Army and the R.A.F. in the field. Altogether some half million troops were carried, including sick and wounded, and 200,000 tons of equipment. The crews taking part were awarded more than 100 decorations, including one V.C., for gallantry in the face of the enemy. This work involved many special problems outside the scope of normal civil transport operations, nevertheless a great deal was learned about short-range navigation aids, and the rapid landing of aircraft which cannot fail to be of value to post-war aviation.

In all these operations the Command carried some 1,600,000 individuals. From the point of view therefore of sheer quantity of flying, the crews and staffs of Transport Command and its subordinate formations had great opportunities for studying transport operations and technique and for increasing the sum total of British experience.



TRANSPORT COMMAND EXPANSION 1945
Monthly Passenger Mileage
Fig. 3.



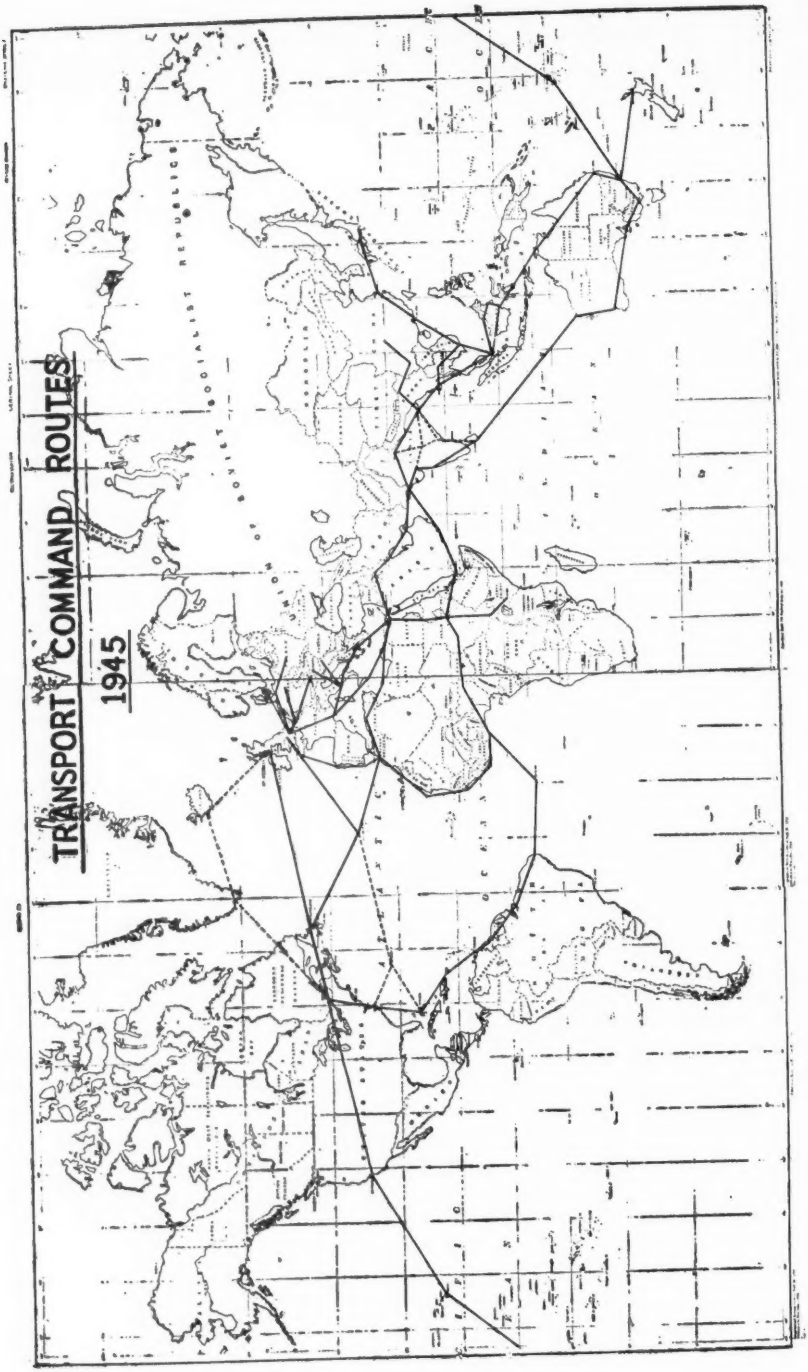
PASSENGER FATALITY RATES
Per 100 Million Passenger Miles
Fig. 4.

Moreover, the quality of these extensive operations as measured in terms of safety does not compare unfavourably with current British civil standards. Fig. 4 shows the published figures for accidents in British Civil Aviation from 1926 to 1946, and set alongside them are the comparable figures for Transport Command, showing separately scheduled services and scheduled services plus trooping.

You will note that I omit special flights and transport support because these two categories were faced with exceptional hazards in no sense comparable with those normally encountered in organised civil operations. Trooping also involved certain risks, especially at its inception in the winter of 1945, when the services were used in the operational redistribution of troops. It was throughout treated as a military operation. A fairer comparison is therefore between the respective scheduled services, which operated moreover on a comparable scale. It will be noted that not only has the downward accident trend of pre-war years been maintained, but it has been greatly accelerated and this in spite of war-time conditions. This holds out great hopes for the future.

It is on the basis of the figures given above, and the experience gained in all parts of the world during this short but strenuous period, that I propose to set out some views under the three headings "Safety," "Regularity" and "Economy." In discussing these matters, I have had in mind the sort of questions which might be of interest to civil air transport and have excluded those of purely military application.

Although the great majority of officers and airmen who took part in these enterprises had had no previous experience of transport work, the Command was fortunate in having a small nucleus who had grown up with civil aviation. The opinions of such men as Air Commodore Fletcher, Air Commodore Brackley, Air Commodore Whitney Straight and Group Captain Dismore, as well as a number of experienced civil pilots, were invaluable. Moreover, the closest contacts were maintained with B.O.A.C. throughout the period. Nor should I fail to mention that anything which may have been accomplished


TRANSPORT COMMAND ROUTES
1945

during the 21 months covered in this review owed its success to the soundness of the foundations laid by Sir Frederick Bowhill.

SAFETY

I put safety first for obvious reasons. All accidents, but especially those involving loss of life, are wasteful and therefore to be stamped out as far as is humanly possible. In normal civil operations the experience of the flying crews who have often spent 5, 10 or 15 years on the job, and know every detail of the routes they are flying, is the accepted guarantee of safety. No such solution was possible in war and the problem was therefore tackled under four headings:—

(i) Systematic training of crews in transport technique.
(ii) Simplifying their task.
(iii) Reducing fatigue.
(iv) Accident prevention.

SYSTEMATIC TRAINING IN TRANSPORT TECHNIQUE.

During 1945, no less than 3,000 pilots—or three times the total of pre-war "B" licences—were absorbed into the transport organisation. While many were transferred from other operational Commands, a number came direct from the training organisation with a total flying experience—dual plus solo—in the region of 300 hours, not a very impressive figure for a transport pilot. Yet any attempt to increase the time spent in basic training would have been at the expense of the transport job, on which depended, among other things, the safety of the 14th Army in Burma. In the circumstances, I consider that a fair balance was struck, but the results achieved were only possible through a scientific study of the problem, based on the great experience which the Royal Air Force had acquired during the war years of training crews to fly in all weathers. The first action taken was to provide regular continuation training, especially in those emergency situations which arise only occasionally.

Aircraft engines and equipment are becoming so reliable that a pilot may fly for his whole career without having an engine cut on take-off, or being forced to overshoot on three engines on a rainy night. Yet with 5,000 pilots these things will happen, and it is therefore only prudent that all pilots should be given frequent opportunity to satisfy themselves that they can take this sort of emergency in their stride. That was the main object of continuation training. It was given first call on the available flying hours.

In addition, all air crew members were given a categorisation test with the object, to quote from the order, "of ensuring that flying personnel are employed within the limits of their skill, knowledge and experience." The test is in five parts and may be of sufficient interest to justify a summary:—

(i) **Flying test.** This includes flying the aircraft with one engine feathered; simulating engine failure on take-off; instrument flying on primary instruments only; instrument let down procedures by at least three different methods; and so on. In fact, tests to prove to the instructor and, of equal importance, to the pilot himself, that he is master of the aircraft and capable of meeting any normal emergency.

(ii) **Technical Knowledge.** This section is included to ensure that the crew members are thoroughly conversant with the technical details of their equipment so that not only can they diagnose faults in the air and rectify them but, where this is impossible, ensure that the correct emergency action is taken.

(iii) **Captaincy.** The ability of pilots as Captains is assessed by the Flight Commander and is based on his personal knowledge of the pilot's character and his ability as a Captain of aircraft.

(iv) **Appearance, Bearing & Discipline.** This is assessed by the Squadron Commander. It is essential that all members of a transport crew should give those who travel with them confidence in their professional competence and in this, smartness of dress plays an important part, as it does indeed on the habits of the crews themselves, especially in such vital matters as attention to cockpit drill and the precision with which they perform their tasks.

(v) **Operational Ability.** Senior Captains are detailed from time to time to accompany a junior Captain on an operational flight and to assess his handling of the aircraft, more especially his judgment in tackling bad weather.

For each section of the test a percentage is awarded, based upon a comprehensive list of points. The lowest percentage attained determines the category which the pilot achieves, just as the lowest marks in each individual item of a section governs the percentage for that section (see Figs. 5 and 5a). This system may seem unduly harsh, but it is based on the belief that weaknesses, no matter how small, cannot be allowed, for when things go wrong in the air it is not average ability which counts, but the manner in which the particular situation is tackled. Only those crew members who achieve the higher

ROYAL AIR FORCE — TRANSPORT COMMAND — CATFORM Pi

CATEGORISATION OF PILOTS
FINAL MARKING SHEET

No. 54321 RANK S/Ldr NAME WINGLESS U.R. R/G P.C.
UNIT 123 SQDN. STATION GREENMEADOW GROUP 467
AIRCRAFT TYPE YORK 1C

TEST	DATE	EXAMINING OFFICER	PERCENTAGE AWARDED 50 55 60 65 70 75 80 85 90 95 100
GENERAL FLYING	7/9/46	J Ftt	
ASYMMETRIC FLYING	"	"	
INSTRUMENT FLYING GENERAL	"	"	
INSTRUMENT FLYING APPLIED	"	"	
NIGHT FLYING	"	"	
EXAMINERS CONFIDENCE IN PILOTS ABILITY	"	"	
TECHNICAL - QUALIFYING	"	"	
TECHNICAL - AIRCRAFT TYPE	7/9/46		
METEOROLOGY	"	"	
WEIGHT AND BALANCE	"	"	
AIR SEA RESCUE	"	"	
PASSENGER HANDLING	"	"	
AIRCRAFT PAPERS	"	"	
RADIO AIDS	"	"	
NAVIGATION & INSTRUMENTS	"	"	
AIRMANSHIP	"	"	
AIR TRAFFIC CONTROL	"	"	
CAPTAINCY	7/9/46	J H Mc...	
APPEARANCE BEARING AND DISCIPLINE	"	"	
OPERATIONAL ABILITY	"	"	

FINAL LOWEST PERCENTAGE 77 CATEGORY AWARDED (E)

REMARKS:- DATE DUE RECAT 17th Mar. 1947

He has been on ground duties for two years and is therefore a bit out of flying practice. Will have no difficulty in recategorising to "A" after more experience on York aircraft.

ASSESSED BY
SIGNATURE
RANK S/Ldr
APPOINTMENT T.C.H.Q.
DATE 17th Sept., 1946

Fig. 5.

ROYAL AIR FORCE — TRANSPORT COMMAND — CATFORM P2

CATEGORISATION OF PILOTS
FLYING TEST MARKING SHEET

NO. 54321 RANK S/Ldr NAME WINGLESS U.R. R/G P.C.
UNIT 123 SQDN. STATION GREENMEADOW GROUP 467
AIRCRAFT TYPE YORK 1C

TEST	DATE	EXAMINING OFFICER	PERCENTAGE AWARDED 50 55 60 65 70 75 80 85 90 95 100
GENERAL FLYING	7/9/46	J Ftt	
BEFORE ENTERING A/C	"	"	
AFTER ENTERING A/C	"	"	
HEATING SYSTEM DEMONSTRATION	"	"	
STARTING ENGINES	"	"	
WARMING-UP & TESTING	"	"	
TAXYING	"	"	
VITAL ACTIONS BEFORE TAKE-OFF	"	"	
TAKE-OFF & CLIMB	"	"	
AUTO-PILOT OPERATION	"	"	
POWERED APPROACH & LANDING	"	"	
ACTION AFTER LANDING	"	"	
SHUTTING DOWN & LEAVING A/C	"	"	
ASYMMETRIC FLYING			
SIMULATED ENGINE FAILURE	"	"	
BAULKED APPROACH	"	"	
BAD WEATHER CIRCUIT	"	"	
ENGINE FAILURE ON TAKE-OFF	7/9/46	J Ftt	
ASYMMETRIC LANDING	"	"	
INSTRUMENT FLYING-GENERAL			
TAKE-OFF & CLIMB	7/9/46	J Ftt	
PATTERN No.2			
PATTERN No.1			
STEEP TURNS			
RECOVERY FROM ABNORMAL POSNS			
ACTION IN EVENT OF FIRE			
INSTRUMENT FLYING-APPLIED			
Q.G.H.			
R.R.			
BABS REBECCA			
G.C.A.			
G.E.E.			
RADIO COMPASS/M/F BEACON			
ASYMMETRIC LET DOWN			
R/T PROCEDURE			
NIGHT FLYING			
TAXYING	7/9/46	J Ftt	
TAKE-OFF & CLIMB			
OVERSHOOT			
POWERED APPROACH			
ASYMMETRIC LANDING/FULL LIGHTS			
POWERED LANDING/RESTRICTED LIGHTS			
ASYMMETRIC LANDING/ RESTD LIGHTS			
EXAMINERS CONFIDENCE IN PILOTS ABILITY			

LOWEST PERCENTAGE 77%

REMARKS-

A creditable performance considering the length of time he has been off flying. Steady pilot.

ASSESSED BY
SIGNATURE
RANK S/Ldr
APPOINTMENT T.C.H.Q.
DATE 17th Sept., 1946

Fig. 5A.

categories are now allowed to carry passengers. Until they reach the necessary standards they are limited to freight services. There can be no doubt that the tests,which were not in full operation until the close of 1945, have thoroughly justified the effort which they entail. Incidentally, without a steady requirement for carrying freight, it would have been impossible to train crews to the passenger-carrying standard in the time available.

SIMPLIFYING THEIR TASK.

That there is room for simplifying the method of presenting information to the pilot will be obvious to anyone who has looked into the cockpit of a modern four-engined aeroplane. Although all agree to the need, the tendency is to ask for more information; in other words the tide is still running towards further complication, and a concerted effort will be needed if the human eye and brain is to be given a task within its capacity when tired.

On the other hand, considerable progress was made on a matter of even greater importance, namely the simplification of the whole art of flying and navigation, especially in bad weather. The weather enters into a great number of accidents; or put another way, there would be few accidents if each day saw a blue sky with a visibility of 30 miles.

Of all the hazards introduced by weather, that of flying into ground which is shrouded in cloud or mist is probably the most serious. There are two problems to consider, the danger when taking off or letting down to land, when the aircraft must, of necessity, be below its safety height, and the danger when in flight that the aircraft, although at an apparent safe height, may have been blown off its intended track towards high ground. The remedy for this latter hazard is the provision of a system of navigation aids which will be available to crews in all circumstances and enable them to maintain their tracks with great accuracy.

It was soon found that the pre-war system of M.F. D/F Stations was unable to handle the greatly increased traffic and that an aid which could be interpreted in the air was essential. By 1945, GEE chains had been installed to cover Western Europe, including France and the Western Mediterranean. They have proved invaluable and a very real contribution to safety.

There are, however, many parts of the world where navigation aids have not reached the same high standard. To meet the needs of these areas a radar warning device carried in the aircraft has been developed and is now undergoing trial. With this, and the other aids available, the risk of accidents caused by faulty navigation should be much reduced.

There remain the periods when so many accidents occur, just after taking off, or when the aircraft is letting down to land, especially on an airfield not equipped with a runway approach aid. Although all the main R.A.F. airfields are equipped with radar beacons giving direct distance measurement as well as bearing, this by itself is not enough and the crew need a map which will show unmistakably the minimum height to which it is safe to come down during the last few miles of the approach, and when orbitting the airfield.

For this purpose special maps have been designed by the Navigation Staff of Transport Command, tinted in bands representing 500 feet clearances above the airfield level so that safety heights can be seen at a glance. This may seem a small point but it is details such as these which often lie at the root of accidents (see Figs. 6 and 6a).

There remain two other hazards which present equipment does not fully meet, namely collision with other aircraft and collision with turbulent clouds. As regards the former the risk can be assessed mathematically and the result is comforting, especially on those days when other aircraft are known to be in the vicinity but cannot be seen. On many occasions during the war densities with operational aircraft were 100 or more times

the maximum allowed by civil regulations, but collisions were rare.

Nevertheless the risk is there and for that reason trials are in hand with a radar detecting device. Unfortunately, with increasing speeds, the conditions which it must meet are arduous, and it would seem that for some time to come aircraft must rely for safety mainly upon routeing instructions and, in the vicinity of airfields, upon good traffic control. The former implies that the crew have at their disposal a system of navigation which will enable them to maintain a precise track, more especially when approaching the airfield. The combination of GEE and radar airfield beacons referred to above gives this degree of exactitude.

The risk of getting involved in a cloud of the cumulo-nimbus type which may be dangerously turbulent would appear from

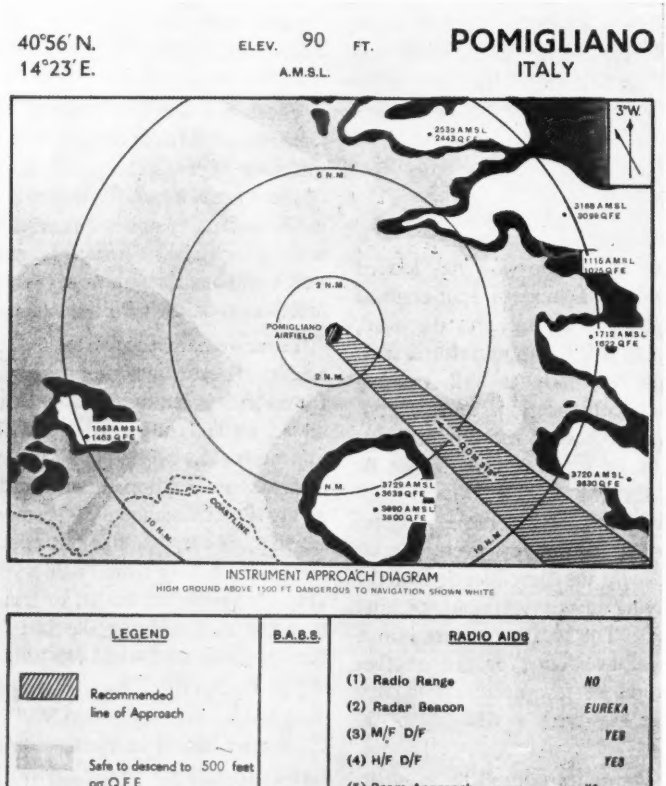


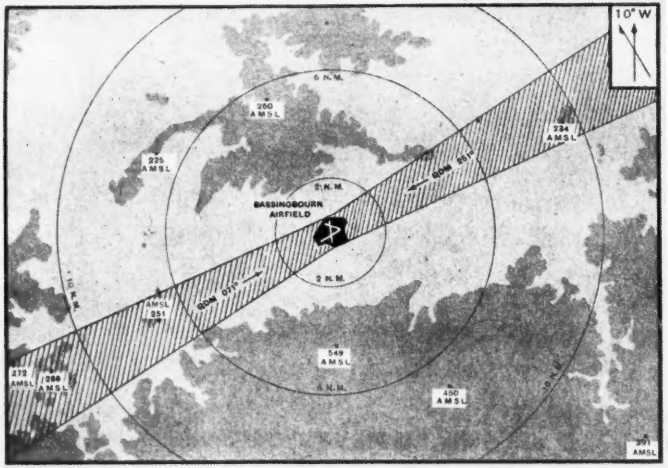
Fig. 6.

A 5 359

52° 06' N.
00° 03' W.

ELEV. 78 FT. A.M.S.L.

BASSINGBOURN
CAMBRIDGESHIRE



INSTRUMENT APPROACH DIAGRAM

LEGEND	B.A.B.S.	RADIO AIDS	
Recommended line of Approach	Q.D.M	(1) Radio Range	NO
Safe to descend to 500 feet on Q.F.E.	25 / 07	(2) Radar Beacon	EUREKA
Safe to descend to 1000 feet on Q.F.E.		(3) M/F D/F	NO
Safe to descend to 1500 feet on Q.F.E.		(4) H/F D/F	NO
		(5) Beam Approach	YES & G.C.A.
		(6) M/F Beacon	YES
		(7) V.H.F. D/F	YES
		(8) Airfield Control Call Sign	YES BASSINGBOURN TOWER
		(9) Approach Control	YES

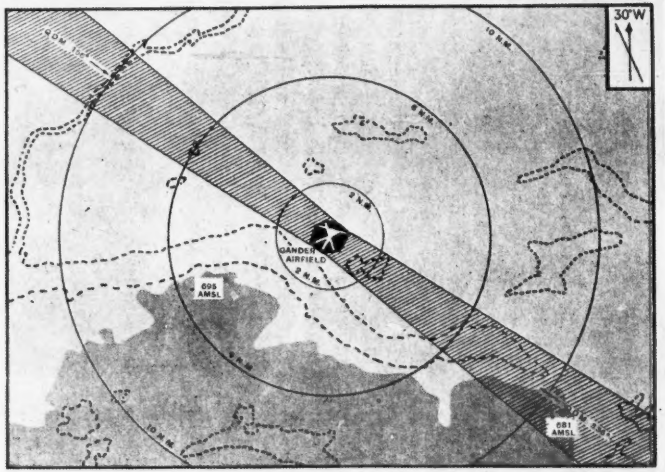
5/A/JULY 1946

RESTRICTED

48° 57' N.
54° 34' W.

ELEV. 493 FT. A.M.S.L.

GANDER
NEWFOUNDLAND



INSTRUMENT APPROACH DIAGRAM

LEGEND	B.A.B.S.	RADIO AIDS	
Recommended line of Approach		(1) Radio Range	YES
Safe to descend to 500 feet on Q.F.E.		(2) Radar Beacon	NO
Safe to descend to 1000 feet on Q.F.E.		(3) M/F D/F	NO
		(4) H/F D/F	YES
		(5) Beam Approach	YES
		(6) M/F Beacon	YES
		(7) V.H.F. D/F	NO
		(8) Airfield Control Call Sign	YES GANDER TOWER
		(9) Approach Control	YES

22/A/AUGUST 1946

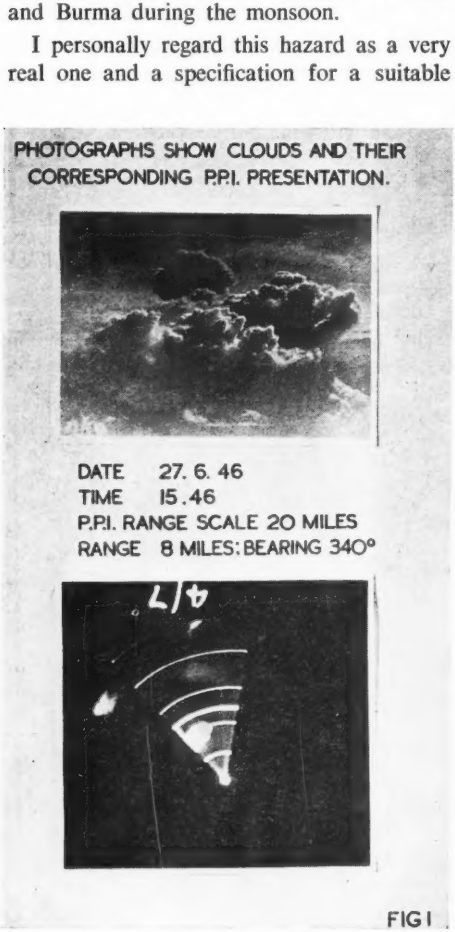
RESTRICTED

Fig. 6A.

statistics to be considerably greater than the risk of collision with other aircraft. During the period under review, six aircraft were lost in cumulo-nimbus while none were lost in collisions with other aircraft. No pilot would willingly enter a really turbulent cloud and good airmanship will generally enable them to be avoided. Nevertheless they are not easily seen at night and for this reason Transport Command aircraft are now timed so as to pass by day through areas where really bad conditions are likely to be found. These areas are fairly well-defined, *e.g.* India and Burma during the monsoon.

I personally regard this hazard as a very real one and a specification for a suitable warning device was put out early in 1945 enabling an experimental set to be tried out by the Telecommunications Research Establishment in South East Asia during the 1946 monsoon. The accompanying illustrations which were taken on that occasion show that dangerous clouds are clearly represented on the cathode ray tube in a form which would enable the pilot to avoid flying into them at night. Of perhaps equal interest is the rather nasty looking cumulus which gave no response on the tube and which was subsequently flown through and found to be innocuous (see Figs. 7 A, B, C and D).

The equipment is now undergoing further tests at the Transport Command development


PHOTOGRAPHS SHOW CLOUDS AND THEIR CORRESPONDING P.P.I. PRESENTATION.
DATE 27. 6. 46
TIME 15.46
P.P.I. RANGE SCALE 20 MILES
RANGE 8 MILES: BEARING 340°
FIG I

PHOTOGRAPHS SHOW CLOUDS AND THEIR CORRESPONDING P.P.I. PRESENTATION.
DATE 21.6.46.
TIME 15.22
P.P.I. RANGE SCALE 50 MILES.
RANGE 20 & 28 MILES RESPECTIVELY
BEARINGS 003° & 020°
FIG.3

Fig. 7A.

unit, to ascertain whether it can help in the negotiation of an active cold front, whether bad icing conditions can be detected, and so on. Representatives of the Ministry of Civil Aviation and the Airways Corporations have been invited to attend the trials which, like so much else of value to aviation, derive from the scientific resources and magnificent team work of T.R.E.

REDUCING FATIGUE.

The third method of increasing safety is to reduce fatigue. Few accidents are directly ascribed to fatigue, yet its effects are probably present in many accidents which are labelled "error of judgment." A scientific study of fatigue during the war under the direction of Professor Bartlett at Cambridge University showed that the performance and speed of reaction of a pilot fell off rapidly when tired, but that in his own estimation he was flying as well as ever. Therein lies the danger. In war there will seldom be enough pilots, and it is therefore essential to know what factors cause fatigue and by eliminating them, increase the number of hours which crews can fly each month without risk.

This is a matter which has continuously engaged attention and the Command has been fortunate to have as a member of its medical staff an officer who is a qualified pilot. By

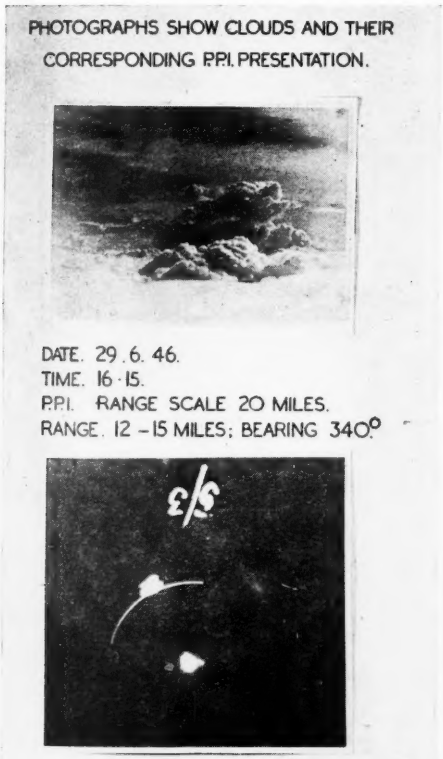

PHOTOGRAPHS SHOW CLOUDS AND THEIR CORRESPONDING P.P.I. PRESENTATION.
DATE. 29.6.46.
TIME. 16·15.
P.P.I. RANGE SCALE 20 MILES.
RANGE. 12 – 15 MILES; BEARING 340°

FIG. 2.

PHOTOGRAPHS SHOW CLOUDS AND THEIR CORRESPONDING P.P.I. PRESENTATION.
DATE 27·6·46
TIME 17·16
P.P.I. RANGE SCALE 50 MILES
RANGE 30 MILES; BEARING 026°

FIG. 4.

Fig. 7B.

flying the various routes himself and living with Squadrons and at staging posts, he reached the conclusion that on long distance flights such as U.K. to India or Singapore, the chief causes of fatigue were to be found on the ground and not in the air.

There are endless ways in which fatigue can occur. Lack of motor transport to take crews to their quarters which in the tropics must be air-conditioned; unsuitable or carelessly prepared food; briefing rooms which do not contain all the information in the required form and so on. It is impossible to overemphasise the importance of the administrative arrangements for ensuring that the needs of crews are properly met and that they get a full night's sleep. This proved to be quite the biggest problem to be solved when building up the trunk routes.

Although during the period to which I am referring fatigue on the ground exceeded fatigue in the air, and probably still does along the trunk route to the East, this must not be taken as meaning that conditions in the aircraft are satisfactory. There is still much to be done, *e.g.* by reducing noise, by providing proper rest accommodation for the crews and, in general, by simplifying their task.

ACCIDENT PREVENTION.

A final point, small but nevertheless

PHOTOGRAPHS SHOW CLOUDS AND THEIR CORRESPONDING P.P.I. PRESENTATION.
DATE 21. 6. 46.
TIME 15. 26
CLOUDS B & C
P.P.I. RANGE SCALE; 50 MILES
RANGE 10&18 MILES: BEARING 000°&010°

FIG. 5

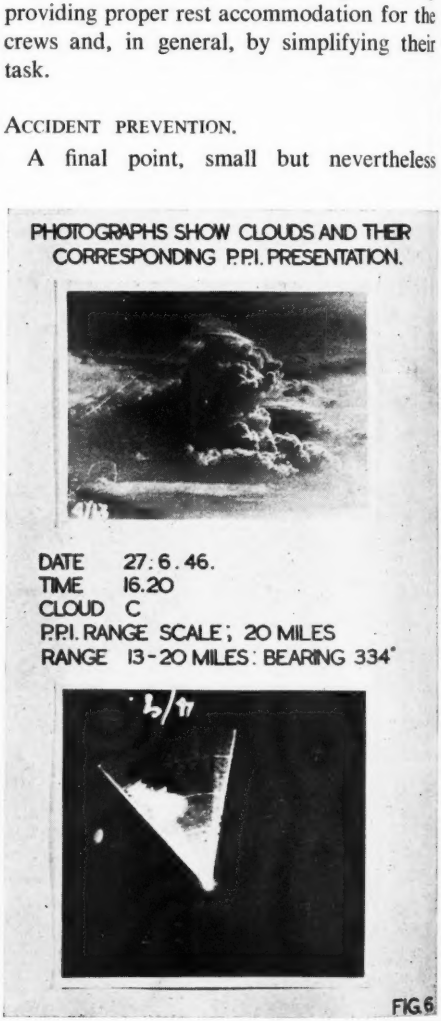

PHOTOGRAPHS SHOW CLOUDS AND THER CORRESPONDING P.P.I. PRESENTATION.
DATE 27. 6. 46.
TIME 16.20
CLOUD C
P.P.I. RANGE SCALE; 20 MILES
RANGE 13-20 MILES: BEARING 334°

FIG. 6

Fig. 7C.

important, is the need for an organisation with the whole-time duty of studying accident prevention. Every accident, however small, is analysed to the fullest extent that the information permits, and the conclusions made known to all in the Command by means of special, quarterly, and annual reviews, and training directives.

I have only had time to discuss one or two of the major causes of accidents but, as everyone knows, there are a legion of contributory causes to almost every mishap. Unless a close watch is kept on every aspect of flying and administration, practices will creep in which carry with them the potential causes of future accidents. Until the art of flying has been further developed there is need for constant watchfulness. There is certainly no room for complacency.

REGULARITY.

I would now like to turn to the second of the series of problems—namely regularity. I need not emphasise the importance of this in a transport organisation, or that in the air the problems are largely those which arise from the vagaries of the weather.

The first essential is for an organised system of communications in order that weather information may be supplied and aircraft subjected to the necessary control when in flight. At the peak of Transport Com-

PHOTOGRAPHS SHOW CLOUDS AND THEIR CORRESPONDING P.P.I. PRESENTATION.
DATE 21.6.46.
TIME 15·27½
CLOUDS B & C.
P.P.I. RANGE SCALE, 50 MILES.
RANGE 5 & 13 MILES: BEARING 350° & 000°.
FIG. 7.

Fig. 7D.

mand activities these communication services absorbed no less than 21,000 men running a world-wide network of W/T and R/T communications, navigation beacons and D/F stations. Much can no doubt be done to economise, but if regularity is to be achieved a first-rate communications system is essential and this will cost money.

As an example of what was achieved in the way of regularity, I would quote the history of No. 147 Squadron which was formed in October 1944 and given the task of restarting air transport to the various European centres as they were liberated. It continued this work until August 1946 when B.E.A. finally took over. The following table shows the regularities achieved in summer and winter:—

		Services Scheduled	Not Completed	Regularity
Winter	Nov. 1944 - Mar. 1945	2532	706	72.1 per cent.
	Nov. 1945 - Mar. 1946	2865	718	75 per cent.
Summer	Apl. 1945 - Oct. 1945	7012	194	97.2 per cent.
	Apl. 1946 - Aug. 1946	782	1	99.9 per cent.

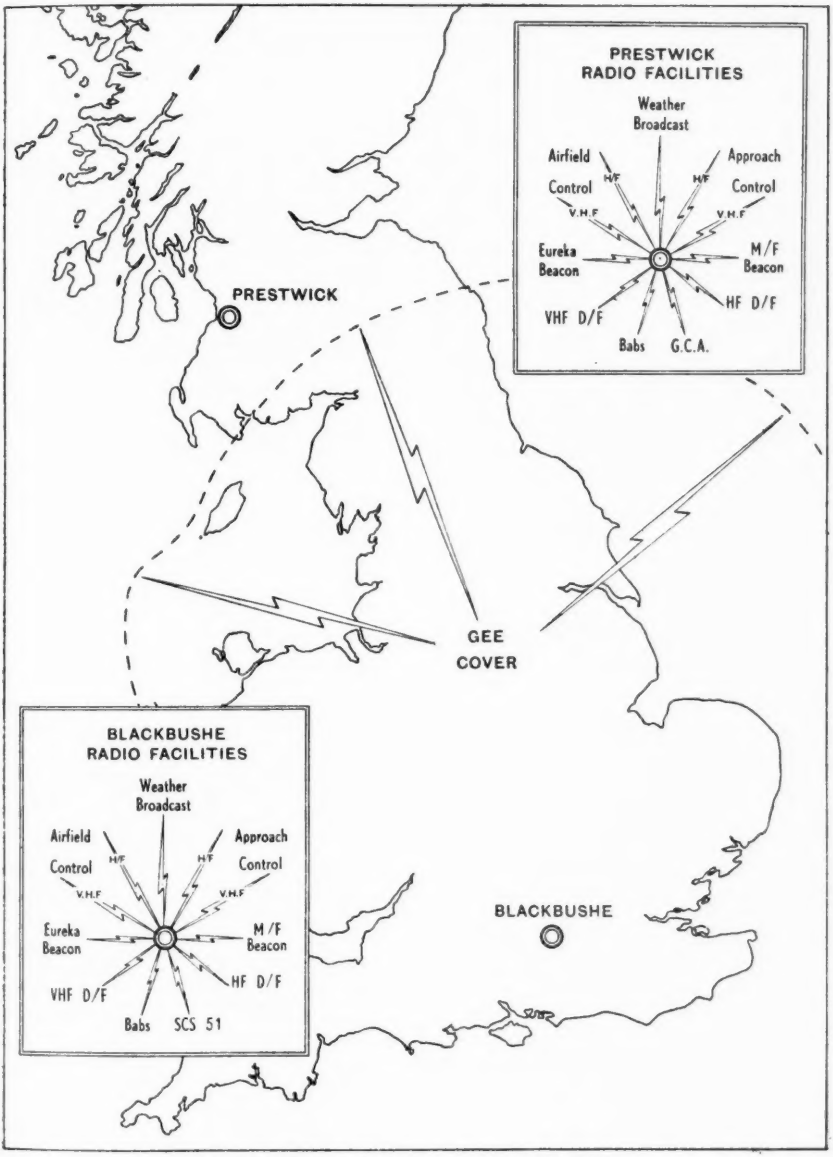
The improvement in 1946 resulted from better communications and navigation aids on the Continent, including the installation of radar beacons, but the impossibility of providing similar facilities at Croydon, the operating base in this country, masks the advantages which can be gained by the use of these aids.

This is shown by comparing the results with those of the military services which are still running, mainly to Germany. From 1st April 1946 until 23rd January 1947, a period including both summer and winter months, 3,150 services were scheduled with a percentage regularity of 98.7 per cent. This great improvement has been brought about by operating from airfields with the necessary radar aids, although all are not yet fully equipped.

An even better indication of what can be done when full aids are available is afforded by the results of the experimental "all-weather" service which was started on 15th September 1945 between Blackbushe in Surrey, and Prestwick. It ran for exactly one year. The route of 400 miles was chosen because it passes through areas notorious for bad weather and poor visibility.

The total number of flights planned was 668 and of these 666 were completed and, what is of equal importance, the start of a flight was never delayed on account of weather either at the point of departure or forecast for the destination. Of the two cancellations the first was to the return northbound service, which on its southward trip had passed through a cold front of exceptional violence which lay across the route. It was deemed prudent not to attempt to pass through it a second time until the aircraft had been thoroughly inspected. The other cancellation occurred when the north/south runway at Blackbushe was out of action and a gusty 40-knot wind, blowing across the other runways, precluded take-off. Fig. 8 illustrates the radio and radar facilities which were available at the two terminals. In addition FIDO (Fog Dispersal Apparatus) was installed at Blackbushe. It was used on five occasions, including one when visibility was less than 50 yards.

Bound up with regularity, and as traffic grows inseparable from it, is the rate at which aircraft can be landed in conditions of poor visibility. Experience in Europe and Burma showed that in clear weather, and with good R/T discipline, as many as 100 aircraft could be landed in an hour on a single strip, and the same number cleared. As soon as the weather made it necessary to adopt instru-



ALL WEATHER SERVICE RADIO FACILITIES
Fig. 8.

ment flight rules, the rate of flow was unlikely to exceed ten an hour.

This was a serious matter, especially when the armies and air forces in the field might be wholly dependent upon supply by air and the problem was given priority for research. On analysis, it was shown that there are three problems. Firstly to navigate the aircraft to the vicinity of the airfield; secondly to pick up the runway beam; and lastly to ensure a touch-down at the precise time planned by the airfield controller.

I wish to stress this last point. If the aim is to achieve a landing rate of 60 an hour, allowing an adequate margin for safety, the maximum error on touchdown in relation to the planned time of each landing must not exceed 15 seconds. This would theoretically give a 30-second gap between adjacent aircraft if the first was 15 seconds late and the following aircraft 15 seconds early. If it is impossible to achieve this precision of timing then the landing interval must be correspondingly increased, so that with a maximum error of the order of one minute the planned landing interval would have to be at least $2\frac{1}{2}$ minutes, a very serious reduction in the capacity of the airfield.

At the time the enquiry started, developments in runway approach aids, especially the excellent BABS Mk. II, had solved the problem of the final approach on to the end of the runway. Similarly, the Eureka radar beacon provided the means whereby aircraft could judge their arrival in the vicinity of the airfield with a timing error not exceeding one or two minutes. There remained the vital link for which no aids were available, namely the "vernier adjustment" which is necessary to convert a navigation error of one or more minutes into one at the point of touchdown not exceeding 15 seconds from the time planned by the controller.

To achieve this there are two requirements. Firstly the airfield controller must be able to calculate a track which if followed by the aircraft will result in its wheels touching down on the runway at the desired moment and secondly, the pilot must be given some simple means of identifying and following this track.

Provided that the aircraft can follow a circular path round the airfield beacon, the first requirement is not difficult to meet and a computor was designed by Mr. Barnett of the Operational Research Section Transport Command, into which the following four factors could be fed: position of aircraft; true airspeed; wind velocity; and time interval to touchdown. The answer then comes out in the form of the radius of a circle, with the centre at the airfield radar beacon, which the aircraft must follow until it turns on to the runway beam. The equipment to allow this to be achieved was designed by T.R.E. as a simple left-right indicator on the pilot's panel, the needle being central when the aircraft was at the desired radius.

Trials started last June and were continued as demonstrations to the visiting delegates of P.I.C.A.O. in September and October. Six aircraft were used — four Dakotas, one Halifax and one Mosquito—chosen so as to obtain the maximum speed range and, in the case of the Mosquito, to show that the system was sufficiently simple for operation by a crew of two.

The standard demonstration consisted in sending the six aircraft away from the airfield on six different headings chosen at random, with orders to turn 180° when they reached the 40-mile circle from the airfield beacon. The controller's task was to accept the aircraft as they called up on their approach, allocate them an orbit on which to fly so that there was no risk of collision, and land them at an average rate of one every two minutes.

For a variety of reasons these figures were never quite achieved although even in the worst weather conditions of very strong winds or ceiling 500 feet, the time required to land the six aircraft did not exceed 15 minutes, a marked advance on anything previously accomplished in instrument conditions.

A great deal was learned and trials will

shortly restart with improved equipment. A rate of one a minute is still some distance off but by no means impossible, excluding for the present visibilities of less than 1,000 yards or clouds below 300 feet.

There is one further method of achieving regularity for a special category of goods which may be of interest. In the autumn of 1945 Transport Command was faced with the task of delivering newspapers and mails to the British Forces of Occupation in Germany. The amount to be carried averaged between 10 and 12 tons a day and had to be delivered to a variety of destinations. All mail was landed at one or more selected airfields for onward distribution by road, but it was decided that such methods would be unnecessarily slow for dealing with newspapers and moreover would fail to achieve the regularity which is so important in this class of work. This on account of the high incidence of fog or very poor visibility over much of the Continent during the winter months, especially in the early mornings when delivery was required.

It was decided that the aircraft should fly round the area to be served releasing packages of newspapers over prearranged points. For the first month the papers were dropped in standard military containers with parachutes attached, but this method was cumbersome and there were difficulties in retrieving the parachutes and containers and repacking them. After some experiments free dropping in mail bags was started, the normal height of release being 500 feet.

In order to assist in finding the dropping points Eureka radar beacons were installed. These gave such good indications during the run in that authority was given for crews to drop "blind" whenever the ground could not be seen, and from this there was evolved a system of release on instruments as the normal method. Of one series of 176 free drops 160 were made on instruments and averaged 308 yards from the beacon. The remaining 16 were visual drops and averaged 250 yards. By the use of this method not only were landings avoided, which are costly and waste time, but the newspapers were delivered whether or not the ground at the destination could be seen. The services ran throughout the winter from September 1945 to March 1946, and were never stopped except by severe icing, and then only because the Stirling aircraft which were being used had no de-icing equipment.

It should be noted that the beacons used for the blind dropping were not specially designed for the purpose, nevertheless they enabled what was required to be achieved and pointed the way to developments which would permit greater accuracy.

It is apparent from the foregoing paragraphs that although much has been accomplished during the war years to improve regularity there are many problems still to be solved. The importance of regularity in air force transport operations, which means the ability to do the job regardless of the weather, is such that further development work is being given high priority.

ECONOMY.

Contrary to general opinion, economy is as vital in Service as it is in civil air transport. In the Service the currency is man-power and the problem is to get the maximum output of useful transport work from the resources allocated. There is never any limit to the amount of traffic offering. In the last war the demand was never satisfied so that every unnecessary inspection, or every delay caused by replacement of a defective part, was at the expense of load waiting to be carried.

The flying hours which were achieved from a strip in the Burmese jungle may well have been less than would have been obtained by an airline engineer with good hangars to work in, staffs which were not changing twice a year, and a steady task to fulfil. Nevertheless we can both agree that a transport aeroplane is "no use on earth" and that anything causing it to be earthbound justifies investigation and the search for a remedy.

In general, the equipment produced during the war failed to stand up to the working conditions to the degree which a transport operator requires, and the expenditure of man hours in keeping it serviceable was inordinately heavy. In saying this I fully appreciate that the aircraft and ancillary industries were overloaded with a mass of war orders and that there were not enough draughtsmen in the country to ensure that sufficient attention was given to the detailed design of every component. Furthermore, when the needs of production were paramount and the life of equipment destined for operational units was measured in weeks or even days, it was not economical to spend too much time and resources on refinements. In fact, the tendency was the other way, and easements and concessions had to be given because in many items the continuance of pre-war standards would have seriously affected production.

Having had of necessity to use what was available it is at any rate possible to have views on the old argument of reliability versus weight; in other words, is it better to make components robust in order that they shall be reliable or must payload be the first consideration?

My own view is that reliability must come first, and that payload will then look after itself, for not only will the total ton/mileage be higher because the aircraft will do more flying, but it will be found in practice that reliability can be achieved without increase of weight provided that the necessary scientific and engineering thought is put into the designs. Some of the lightest equipment has proved the most reliable, a triumph for its designer.

POWER PLANTS.

What we all desire as a first stage towards economical transport flying is an engine which will run without trouble for at least 1,000 hours; but if that cannot yet be achieved and we are forced to accept some lower figure, it is essential that within that figure the engine shall be free of defects. This is at least as important as length of life, because nothing is more wasteful than the need to replace engines or major components at some unforeseen point along the route. As an example, at one stage of the trooping programme with 130 aircraft in daily flight along the route to India, there were no less than 20 aircraft held up for engine changes. Later, owing to more stringent rules concerning engine handling, this number was reduced to seven, but even seven aircraft static on the route is far too high a price to pay.

Apart from the failure of major components necessitating an engine change, much work is entailed in maintaining the great number of engine-driven components. The ideal is that the power plant should consist only of the engine and the associated equipment necessary to its functioning, all items being capable of running 1,000 hours without attention. Other ancillary services should be divorced entirely from the power plant and installed where they are accessible and easily replaced. There is much scope here for ingenuity; for instance, it would be magnificent if it were found possible to get away from the 2BA nut which simply asks to be dropped into the works.

Examination of the maintenance costs for 1½ millions of power plant running hours, shows that for every running hour approximately one man-hour was required for maintenance in the field. Rectification of defects accounted directly for 1/10th of this time, but much of the remaining 9/10ths was expended on power plant building necessary because the engine had such a short life between overhauls, and on the replacement of components —often difficult to get at—in case they should fail if allowed to run longer. The million-and-a-half man-hours represent only the direct costed time of doing the job and it is probable that they should be doubled to cover all the preventive inspections which take place because of the fear of trouble. There is obviously much room for develop-

ment before power plants can be said to meet the requirements of operations in the field.

AIRFRAMES.

Airframes, in general, do not give overmuch trouble, but there are a number of minor defects which could probably be cured by better detailed design. As an example, rivets fail, with consequential skin panting. This, in turn, leads to minor structural failures. Modifications are then necessary but anyone who has had dealings with modifications knows what they cost in time, money and temper. The difficulty of making joints, especially cabin canopies, watertight brings endless trouble. It causes electrical shorts and instrument failures which, apart from the inconvenience to crews, might endanger the aircraft's safety through failure at a critical time of the radio and radar services. There is also the fire risk. Corrosion is another problem, particularly of aircraft operating in extremes of climate, a secondary effect being, of course, rivet failure. Materials which are proof against corrosion are urgently required since the labour spent in combatting corrosion is a very serious drain on manpower.

Tyres are another prolific source of trouble. In spite of improved methods of tyre inspection which have raised the average landings per tyre for the York and Halifax from 20 to 70, the aim of 200 landings per tyre is still far in the distance. Cuts, beyond unit capacity to repair, account for 70 per cent. of all the tyres discarded. If, therefore, cuts could be eliminated, the tyre bill would be reduced by 2/3rds. Much can be done by keeping runways and perimeter tracks free from stones and other oddments, but it takes about a week to sweep the runways and tracks on an average airfield using the present equipment, while on some of the overseas airfields the flints protruding from the concrete surface will only have been polished and sharpened by the process. Improved runway surfaces, which of course cost money, and more efficient sweeping devices, are urgently required if the tyre bill is to be kept down.

ELECTRICS AND INSTRUMENTS.

The lives of electrical and instrument equipment —even where any can be given— bear little relation to those of the power plants or airframe. It is therefore difficult to phase the servicing of this equipment into that of the rest of the aircraft. The root cause of the troubles with electrics and instruments is again the lowering of standards occasioned by the war. Generators, starter motors, voltage regulators, accumulators, cables and instruments, all have the same inherent failing—they do not last. Primarily their design is insufficiently robust to withstand the loads which they must carry, or the vibration to which they are subject. Unfortunately the replacement of electrical and instrument components is usually tricky and tedious and calls for skilled and careful personnel who are not easily found in war. It would certainly appear more economical to design for 1,000 hours' reliable working and thus cut out this wasteful and costly servicing and testing.

SPARES.

There is one further point which arises out of the preceding paragraphs, namely, spares. So long as failure of components has to be accepted an adequate and properly distributed supply of spares is essential, yet in spite of all the thought given to this problem during the war, we do not seem to have achieved a satisfactory and economical solution. The loss when spares are not immediately available often far exceeds the cost of a most generous initial supply because:—

(i) Valuable carrying capacity is wasted when aircraft are forced to wait for replacements.

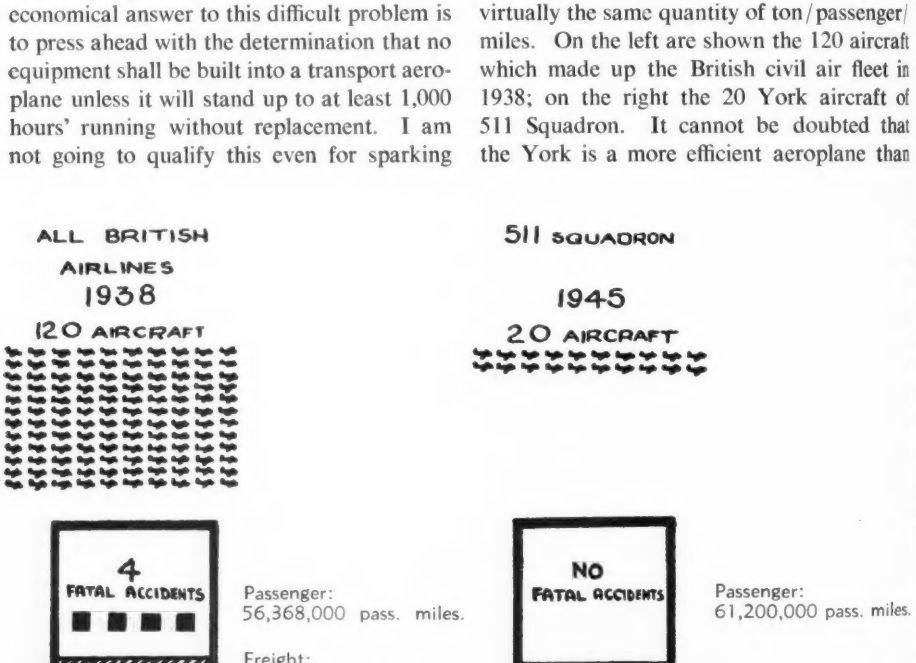
(ii) In desperation, serviceable items are taken from another aircraft or power plant undergoing routine inspection or

for other reasons unserviceable, thus entailing a double replacement.

(iii) Extra stocks of complete units have to be held because spares to make components serviceable are not available.

To sum up this section; the war has brought us face to face once more with the problem of quality in aircraft equipment. There will always be arguments to show that high standards cost too much in manufacture, in weight, or in both, but my personal belief is that they do not, and that the only economical answer to this difficult problem is to press ahead with the determination that no equipment shall be built into a transport aeroplane unless it will stand up to at least 1,000 hours' running without replacement. I am not going to qualify this even for sparking plugs. Others who have had oportunities of exact costing over a longer period may take a different view. I frankly admit that mine is based on a period when circumstances did not permit detailed cost accounting to be maintained, and is in relation to operations in the field where permanent base installations are often lacking.

In case it should be thought that I am asking too much, I have included a comparison (Fig. 9) between two fleets of aircraft which, in a year's operation, completed virtually the same quantity of ton/passenger/miles. On the left are shown the 120 aircraft which made up the British civil air fleet in 1938; on the right the 20 York aircraft of 511 Squadron. It cannot be doubted that the York is a more efficient aeroplane than



PROGRESS IN AIR TRANSPORT
Fig. 9.

its pre-war counterpart, or that progress has been extremely rapid, however slowly we may sometimes think we are moving.

I would like now to turn to another much debated matter, namely the value in transport operations of long range and high speed. We were fortunate in being able to make a direct comparison between the carrying capacity of the Dakota and the York, since both were used on the trooping route to India. Any complete costing would, of course, have to include capital expenditure and a host of other items which are not available. Therefore I have deliberately restricted the comparison to two items, firstly, the number of pilots required, and secondly, the manpower employed along the route; the latter depending primarily on the number of refuelling stops.

The shorter range and slower speed of the Dakota necessitated the provision of nine refuelling and rest points on the round trip as against five for the York. At each of these stations, in addition to the men to service the aircraft, others were required to man the signals communications and airfield services; to attend to the needs of the personnel in transit; to run the motor transport, and to perform a host of other duties. The total numbers employed at each of these refuelling bases varied between 600 and 1,000 and the cost was high, especially in such places as Bahrein and Sharjah in the Persian Gulf. The longest stage on the Dakota route was 880 nautical miles in a scheduled flying time of seven hours. For the York it was 1,300 nautical miles in a flying time of seven and a half hours, an increase of almost 50 per cent. for only an extra half-hours' flying.

From statistics of the average times for the two types of aircraft to complete a round trip, and from the numbers of men established on the routes for the trooping operations, it has been possible to estimate the gain in transport that resulted from the greater range and speed of the York. The actual gain was, in fact, considerably higher because of the greater carrying capacity of the York, but in estimating the advantage of increased range and speed this factor has been discounted and the two aircraft assumed to have the same carrying capacity.

On this basis 35 per cent. more troops were moved for each crew employed because of the increased speed of the York, and 65 per cent. more troops were moved per person manning the route because of the greater range of the York. Considering the cost of training air crew to the transport standard, an increase of 35 per cent. in the numbers carried per crew is an important contribution to economy, while the saving in manpower along the route is even greater. All this for an increase in speed and range by no means spectacular.

In concluding this section I am aware that I have only dealt with a few of the many factors which, when properly balanced, make for genuine economy. As a consequence, there may be some who will query the soundness of the conclusions reached. I can only say that in relation to the particular operating conditions described in this lecture they appear to be true, and to represent those factors whose pursuit will do most to secure the real economy which is so vital in all transport operations.

CONCLUSIONS.

I would like now to sum up in broadest outline what I think the Air Force has learned in its venture into the realms of air transport. Firstly, I think we can say that it is possible to build up a transport service in a very short time and that although this involves certain risks, they can be minimised by organisation, training and team work. In the case of Transport Command this team embraced the other R.A.F. Commands, especially those overseas, and the many departments of the Air Ministry and the Ministry of Aircraft Production.

During the war, and this is still true today, no large organisation could be self-sufficient, but had to be prepared to obtain its results

through a form of combined operation or combined enterprise, with other equal partners. This is never easy to work and does not work at all unless played in accordance with the rules of the game, which unfortunately are themselves only in process of evolution. Nevertheless great advances were made during the war and combined planning and combined execution became the accepted operational method in transport, as in most other forms of warlike activity.

The broad team work to which I have referred above must be reproduced within the transport organisation. Without the spirit of a team the expansion which was achieved would have been impossible. Great importance was attached to good liaison between the crews who were flying and the staffs who were planning and directing. So far as was possible, commanders and their staffs were selected from officers in full flying practice, who therefore possessed first-hand experience in the use of the many new aids to navigation which were continually being developed. There was also a free interchange between staffs and squadrons, thereby ensuring that the two partners had the fullest knowledge of each other's needs and problems.

Many of these problems would have been insoluble before the war, but the rapid development after 1939 of methods of training, aids to navigation—especially radar aids—and perhaps most of all, the experience gained in operational flying, enabled the expansion to take place as planned.

The Command has now shrunk to a shadow of its former self, but this has the compensation that more time can be devoted to a study of the problems which have been outlined in this lecture. Development work, although primarily directed to air force operations, may well have applications in civil flying, and close contact is maintained with the Ministry of Civil Aviation and the Airways Corporations, from whom we hope to continue to learn much.

In closing, I would like to pay tribute to all those who took part in the various enterprises which have been described and especially to those too often forgotten officers who did the planning, without which no large organisation can survive, let alone grow. That the officer mainly responsible, Air Vice-Marshal Collier, is now at the Ministry of Civil Aviation will, I hope, be regarded as fortunate. Without his work the Command would never have achieved what it did.

DISCUSSION

Mr. E. Gold (Deputy Director, Meteorological Office): As one who had spent a lifetime dealing with weather problems, he paid tribute to Transport Command for the way they had overcome the difficulties of weather. They could not select their weather, but just had to carry on with their operations and their work had been magnificent. Mankind was always endeavouring to make his operations independent of weather, but even outside the field of aviation, the temperature in the lecture hall showed that he had not completely succeeded; and in the field of aviation it was an extremely difficult matter.

Commenting on the author's statement that about 11 per cent. of the accidents occurring in 1946 were those in respect of which the weather was the primary cause, he emphasised the difference between the weather being a primary cause and the weather forecasts being wrong. Obviously, if they only flew when the weather was completely favourable, with blue skies and visibility for 30 miles, they should not do much flying in this part of the world; and the function of the meteorologist in regard to flying such as that of Transport Command was not to prevent the aircraft flying but to warn the crews of the conditions they would experience in the course of their flights. It was inevitable that, in spite of the fact that warnings of bad weather had been given,

there should sometimes be accidents in which the weather played a primary part.

Of the information which was given to pilots concerning the weather to be expected on their flights, that which related to the weather they would experience at their destinations was of vital importance, as had been emphasised in the paper. It depended upon a proper system of communications and proper warning in advance.

During 1946 there had been no accidents attributable to wrong weather information to civil aircraft for which the British Meteorological Service was responsible for providing information. He made that statement categorically, and emphasised it, because there was so much misapprehension in people's minds with regard to the matter.

Naturally, progress was being made. As shown by the paper, in regard to cumulo-nimbus there was much co-operative work between the meteorological officers and T.R.E. and radar officers; and that represented only the first stage, and not by any means the complete investigation. But it served to show how extraordinarily valuable the further development would be in enabling pilots to avoid these cumulo-nimbus dangers—often easy to avoid in daytime, but difficult to avoid at night.

There were two aspects of the problem of economy of operation; there was the information which enabled a flight to be made, and information concerning the course to take. A meteorological officer had recently devised a method of computing the best course for a flight across the Atlantic. In respect of a flight which, by taking what was called a single heading course, would occupy 15 hours, he was able to compute a course which would occupy two or three hours less. The officer concerned believed that the method could be so perfected as to enable the computation to be done in one hour. Apart from the convenience of saving two hours out of 15, that reduction of flying time represented an enormous saving of fuel, the weight of which could be converted into payload.

That was one of the ways in which meteorology could contribute effectively to economy of operation, which was of importance not only to civil aviation, but to all forms of aviation.

Air Vice-Marshal Sir Conrad Collier (Ministry of Civil Aviation): In civil aviation planning was a headache. When planning international routes during wartime, one great advantage was that a great nation and a great Empire such as theirs could centralise planning; by means of agencies overseas they could plan a big operation throughout the world with a relative certainty that there would be uniform standards and uniform equipment, and that things would be where they were wanted at the right time, as centrally planned.

Planning was not his province in the Ministry but he was sure that the officer responsible, who was present at the meeting, would agree that it was a difficult problem to get the same sort of pattern, first of all within the international P.I.C.A.O. framework—an organisation which was not yet fully effective. This pattern involved getting aircraft flying to standard, well organised ground services, and using the same procedures with adequate communications from point to point, and was complicated by the fact that the R.A.F. was being withdrawn and it was found that there was no one left to provide such services. They had come down to the problem of cooks and butchers at places such as El Aden, where the R.A.F. would not be staying, and it would be necessary to find out where all the cooks and butchers, and so on, were to come from to keep those short-stage posts in action.

He agreed whole-heartedly with the lecturer in advocating long-range, thereby avoiding all the small ground organisations which cost so much and which meant so much forecasting and planning and communications. It seemed to him that, as they went ahead with civil aviation, they would be compelled, for economic reasons, to plan long-

range operations and to order aircraft accordingly. In the Ministry of Civil Aviation he saw only the ground services side, and could not speak for the operators; but he must emphasise that planning was a headache in civil, as compared with military, transport.

Major R. H. Mayo (Fellow): The author had not said much about icing conditions. He had disclosed the vast amount of flying that had been done all over the world, and had revealed figures relating to the regularity of the Blackbushe - Prestwick service, for instance, which could not fail to bring out their utmost admiration. But if the icing menace were so serious as it was believed to be, the aircraft must have experienced icing conditions on a great many occasions. Therefore, he would be extremely grateful if the author could give information as to the seriousness of the icing experienced, both as regards the airframes and the engines. Perhaps he could say whether, and to what extent, the aircraft had been provided with de-icing or anti-icing equipment, and how far that equipment was effective; and perhaps he could give information as to whether icing had resulted in any appreciable number of accidents and how serious they were. He asked the question because Transport Command had had so much more experience of flying in bad conditions than any civil aircraft operating company.

Another question, which he rather hesitated to raise in the presence of the Chief Inspector of Accidents, was whether the overloading of aircraft in Transport Command, which had been a military necessity, had in fact resulted in an appreciable number of accidents. They had heard a great deal recently about the all-up weight of a certain type of aircraft, and he would like to know whether, in Transport Command, serious losses had had to be faced because of military necessity, or whether the aircraft could really operate at overloads without serious trouble.

The extent of the operations of Transport Command was an amazing revelation, and the success achieved was a matter for the greatest admiration.

Air Marshal Cochrane: Icing was one of those matters about which everybody had forebodings, but it seemed almost impossible to obtain any really scientific statistical data. The Blackbushe-Prestwick services ran throughout last winter, on many days on which icing was forecast, but without experiencing any serious difficulty with it. They were flying Dakotas, on which the de-icing equipment was fairly complete. On the other hand, the Stirlings which had no de-icing equipment were not allowed to fly if icing conditions were forecast. He believed that B.O.A.C. had had as much experience as anybody of icing conditions across the Atlantic, but in the operations of the Command it had not proved a serious problem, although it had frequently been a source of worry. Whether that was because serious icing conditions were rarer than people thought, or whether the pilots had become skilful in preparing their flight plans, or whether the machines were kept on the ground when conditions were bad, or whether the immunity was due to a combination of all three, he could give no precise figures.

During the war the Dakota was loaded to 30,000-31,000 lb. So far as he was aware, there were no accidents at take-off which could be attributed to the loading, but of course the risk of engine cut-out at take-off was small; although had it occurred, the aircraft could not have remained airborne.

Sir W. Welsh: It was clear from the paper that Transport Command had been confronted with some great problems; the figures were most interesting, and at the back of them there was the usual efficiency to which they were accustomed in the R.A.F.

It seemed that comparisons between an organised service such as the R.A.F. or any big Government Service on the one hand, and civil aviation on the other, would not always give the right answers. No one knew

better than he that before the war the R.A.F was undoubtedly the Cinderella of all the Services. But if the R.A.F. were the Cinderella of the Services, from what he had seen and read of civil aviation it would appear that it had not even any parents or relations. It must have had some parents, of course, but one could not believe that those parents were even enamoured of each other. However, all healthy problem children were difficult and from a sound organisation such as that of Transport Command, they should be able to derive a great deal of benefit for future development.

With regard to icing difficulties experienced in connection with trans-Atlantic flights, he was sure there were records in B.O.A.C. from which figures could be supplied, indicating how many aircraft had been diverted or turned back, or whose departures had been postponed, because of icing. He would hate to suggest that it was not a problem and that they should give up trying to solve it.

Air Commodore Vernon Brown (Chief Inspector of Accidents, Ministry of Civil Aviation): There had been a great many accidents caused by icing about which they knew nothing. One example, in which information had come to hand, pointed to icing as being the cause. A structural failure had occurred to a certain type of aircraft when in the air, and there was a crash. While one of his Inspectors was groping around the wreckage, trying to find first-hand information as to the cause, a farm labourer had come along and had said that, when working in a field a few hundred yards away at the time of the accident, something had whistled past his head and had buried itself in the ground. Thinking that it might be of importance, he had dug it out and had found it to be a piece of ice about 2 ft. 6 in. long, one side of which was in the shape of a perfect curve. If that had not been found it would have been difficult to say that the pilot had lost control on account of icing.

It was probably true that within certain limits they could get away with a certain amount of overloading; but a matter of more importance than overloading in itself was the position of the centre of gravity. There had been a great number of accidents caused by the malpositioning of the C.G. In that connection he recalled some correspondence he had had in 1939 with Sir R. Hill, who had suggested the slogan "Let us try to make the R.A.F. centre of gravity conscious." That still applied to everybody.

Air Marshal Sir Alec Coryton (Controller of Supplies (Air), Ministry of Supply): The author had referred to fatigue on the part of air crews being due largely to the jungle of instruments which had to be watched, and to the terrific waste of man power in connection with the maintenance of those instruments. The simple solution was to get rid of them; he would like to see the formation of some sort of League which would concentrate on the simplification of the aircraft cockpit and its instrumentation. There were too many experts in these days concerned with various gadgets, instruments and so forth, all insisting that theirs must be fitted; but everybody concerned with the Aircraft Industry would like to see the development of some plan which would really simplify the cockpits and their layout.

Air Marshal Cochrane: What was badly wanted was an instrument which would indicate the power the engine was giving; they might then do away with many of those at present fitted, which even in combination only gave part of the answer.

Mr. I. Bowen (Ministry of Supply, Fellow): He referred to Air Marshal Coryton's plan for simplicity in aircraft instruments and said that as one responsible for instrument design he had hoped this year would have brought some respite from the demands of the Air Staff for more and more instrumental equipment. Unfortunately, the Service tended to yet more equipment and by the very nature of their constitution the Ministry of Supply must make every effort

to meet the demands. Referring to the lecturer's remarks on reliability of electrical instrumental equipment, he agreed that under wartime stress it had become difficult to maintain the highest standard of workmanship in the factories; nevertheless, the results achieved were encouraging.

Transport Command had maintained a close summary of all defects since January, 1946 and the statistics so compiled were proving invaluable in showing the trend of the defect rate and in focusing attention on weak points in design and in maintenance, in respect of which remedial action could be taken.

The lecturer had proposed a minimum trouble-free life expectation of 1,000 flying hours for aircraft equipment. That figure was agreed as being desirable by the designers, and it was interesting to compare the actual performance of instruments and electrics with that desirable standard, bearing in mind that 1,000 hours of flying approximated to a year in the life of a York aircraft.

Because the life history of each item of equipment in the Command could not be traced readily, a figure giving the number of item hours per defect provided the only indication of life expectation. That figure had been compiled for each of the various items over the period January to September, 1946, every defect, suspected defect or accidental breakage being included, as also were multiple reports during a flight of a single original defect. The figures were as follows:—

Direction indicator	1,050	item	hours	per	defect
Engine speed indicator	1,950	„	„	„	„
Turning indicator	3,000	„	„	„	„
All other instruments except oil pressure indicator and artificial horizon, over	3,000	„	„	„	„

The artificial horizon had proved particularly troublesome, and a safe life period of 160 hours had been imposed on that instrument. A life of 1,000 hours or more would be achieved only when the electric artificial horizon came into service, so eliminating the entry of dust and moisture-laden air into the instrument, which was the greatest source of trouble in the present pneumatic model.

The particular oil pressure indicator referred to had entered the Service too early in its development and, although the defect rate was falling, the present design gave but 400 hours' flying per item defect. A detailed investigation of the effects of engine vibration on that engine-mounted instrument had shown where its design was still deficient, and remedial action was in train.

An analysis of Transport Command reports on electrics gave the following figures:—

Generators	1,450	hours	per	item	defect
Regulators	4,000	„	„	„	„
Accumulators	1,500	„	„	„	„
Electric Circuits	860	„	„	„	„

Athough the figure for regulators was 4,000 hours per item defect, the figure over the January-September period for the adjustment of regulators was but 400 hours; however, more precise instruction and training in regulator handling, and particularly in leaving well alone, had already more than achieved the 1,000-hour figure.

He had hoped that the author would have said how many men were employed on the ground to make adjustments to equipment to to compare with the 2,000 required to maintain communications. It seemed that there had been unnecessary adjustments, such as balancing the output of generators to a fine limit when the generators did not need it. Without that fine adjustment, the regulators could operate for more than 1,000 hours without trouble.

Comparable figures now available for aircraft in the hands of civil operating companies showed that artificial horizons were achieving from 500 to 1,000 hours per defect, whereas direction indicators and engine speed

indicators were not performing so well as they were in R.A.F. Transport aircraft, the figure being well under 1,000 hours.

A serious disclosure made in the Transport Command records was that, apart from those instruments and electrical items which were subject to special remedial action on account of abnormal defect rate, the performance was gradually but consistently deteriorating, and that would seem inevitable under a system whereby equipment, unlike airframes and engines, was permitted to fly on without overhaul or replacement at stated periods. In the absence of a set replacement period, the average age of equipment in a contracting command must tend to increase, and the defect rate must rise with increasing average age. The solution lay in determining by operational research the true life expectation of new equipment, and in adopting a maintenance system which would ensure the return, whether defective or not, of equipment to factory for re-conditioning at the expiry of the life period.

The work which Transport Command was performing in recording its troubles so meticulously was proving of great value; for the first time a spotlight was being focused on the performance of individual items of equipment, giving a sure indication of the ways in which the robustness of that equipment could be improved.

Air Marshal Cochrane: While agreeing with the hours per item/defect given by Mr. Bowen, it was necessary to remember that much electrical and instrument equipment was removed and serviced or replaced by a serviced item long before the hours quoted were reached. This servicing, which experience had shown to be necessary, ate up the man-hours. What he was suggesting they required was equipment which did not require this interim servicing, but would run for 1,000 hours before it had to be touched.

Air Vice-Marshal J. N. Boothman: Transport Command was in a position different from that of the rest of the R.A.F. Whereas the air crews in the rest of the R.A.F. were ordered, while in the air, to make diversions and had to go when and where they were told and return when and where they were told, the crews in Transport Command made up their own minds to a certain extent, having the right to go and the right to stop. Whether or not in the future the air crews would be able, to some extent, to make up their minds was a matter to be considered; whether they could be expected to have knowledge of what was happening in the outside world to enable them to do that, as opposed to being controlled from a control centre.

Mr. F. Radcliffe (Handley Page Ltd., Fellow): The termination of the World War in 1945 had seen Transport Command the biggest Command of the R.A.F. Its commitments, as the map indicated, were truly world-wide. Undoubtedly a great mass of experience and data was accumulated; but were they making the most of that information to-day for civil airline operations? He hoped so.

The importance of safety had rightly been stressed by Sir Ralph above all else. Of what use was speed, if they could not deliver the goods safe and sound, whether men or freight? Sir Ralph's insistence on attention to cockpit drill would appear to have been underlined several times recently by accidents which had occurred to civil air liners. The complications of a modern flight deck were a headache to designer and operator alike, and they had not by any means reached finality.

Pressurisation, with which, until now, Transport Command had fortunately not been involved, was now presenting quite a formidable addition. How important it was, therefore, that they should make a vigorous attack on all duplicated equipment in aircraft, because they had not reached international agreement.

Radar and radio were two items which required such attention, especially as they

contributed so important a part in achieving the low incidence in accidents quoted by Sir Ralph. The impression was gained that America would be using one type of Radar while Great Britain would be using another. That would lead to duplication of equipment, an encroachment on payload and—what could be more regrettable?—accidents caused by misunderstanding. If they and America could reach common agreement, a big step forward towards world agreement would have been realised.

He endorsed the author's remarks regarding the counter-action to be taken to combat crew fatigue; sound-proofed cabins would do much to assist during flying, as would also easier access to crew stations. On the ground, the chief complaint at present seemed to be not so much the need for air-conditioned rooms in the tropics as for quarters which were really quiet and were located away from the rest of the men. Too often crews had had to sleep in dormitories, where it was impossible to ensure the quiet and seclusion necessary for sound sleep.

The practice by Transport Command of issuing regular statements on reasons for unserviceability was useful. A six-monthly appreciation of progress, or otherwise, in meeting the causes of unserviceability would assist greatly in making known to designer and operator alike the work which must be pressed ahead.

The remarks by the lecturer on economy of operation were also useful, and the ideal of 1,000 hours' useful life was, in principle, excellent. But he felt that to ask for the same standard for sparking plugs was to ask too much, for, as their replacement cost was small in comparison with their importance, it would surely be a better proposition to scrap them after 500 hours.

The call for that length of life for piston engines served to emphasise the urgent need to press on with the development of trouble-free running of gas turbines, if they were to give the reliability and life expected of them.

Information on maintenance requirements, which Transport Command had found desirable, should be made available to the designer from the inception of a new design; and the fulfilment of those requirements should be the joint responsibility of the user and the designer.

Would the author give information on the special loads which Transport Command had had to transport and particulars of the specialised features they had produced for use on standard R.A.F. transports? He appreciated that that information could well constitute a separate lecture, but he urged that some mention should be made now.

He would also like more information about the dropping of mails over Germany. The average distance from the target was given as being in the region of 300 yards. But he did not think that that was really a fair statement; what was the extent of the scatter on either side of the target? If one consignment were dropped on the target and the next was 600 yards away, the average was still 300 yards.

Air Marshal Cochrane: In replying to Air Vice-Marshal Boothman; it was a recognised principle that on route operations Transport Command crews could not be made to fly against their judgment; on the other hand, their intention to take off could be over-ruled by a senior officer if he thought they would be taking undue risk. He was not speaking of operations in face of the enemy, of course.

With regard to diversions, there were two types, Grade I being mandatory, and Grade II advisory. For example, if there were a crashed aeroplane on the runway, so that the incoming aeroplane could not land there, or if there were a wind across the runway which was beyond the limit, or some reason of that sort, the instruction would go out as a Grade I diversion. But the more normal practice was to inform the crew of the conditions and suggest alternative airfields. It was then the responsibility of the captain to decide in the light of the many other factors which would be known to him alone.

Mr. Radcliffe had referred to information being forwarded by Transport Command to the civil operating companies; copies of all Transport Command's Summaries were sent to the engine manufacturers. Further, a liaison officer from the B.O.A.C. worked at Transport Command Headquarters, saw all important papers and passed on to the Corporations anything which he considered to be of interest. In the same way, Transport Command received all their statistics on engine running, and so on. Thus, each knew what the other was achieving. Longer term appreciations were also being prepared.

The suggestion had been made that sparking plugs should be excluded from his 1,000 hours' category, but with the standard of mechanic available in war it was best to leave a thing alone for as long as was possible. It was surprising how many mistakes could be made even in changing a set of plugs.

With regard to dropping mails, a distance of 600 yards from the target would be about the maximum. But that result was attained when aided by a normal airfield approach beacon which was not designed for the purpose. However, he considered the results were encouraging; certainly they were better than he had expected.

Mr. N. E. Rowe (British European Airways, Fellow): The picture which Sir Ralph had given of what air transport could do should be of the greatest encouragement to civil aviation generally. He felt that Transport Command could approach the ideal much more nearly than could national enterprises engaged in civil air transport, for many reasons, such as the continuity of command all the way along the routes, the consequent easing of the communications problem, and the fact that there had been no difficulties such as those associated with the crossing of national boundaries. Nevertheless, the paper was full of lessons which could be studied with great advantage, especially those which related to improvement of details, and the measures which had been found to be fruitful of safety in the Command.

There were some respects in which civil aviation differed from Transport Command, notably that of passenger comfort. He did not know how far that was looked after during the trooping operations, but those engaged in civil aviation had to pay special attention to it, particularly in bad weather. In his paper the lecturer said that during a flight from Blackebushe to Prestwick on one occasion the aircraft was strained, yet it was thought fit to go on through such bumpy conditions. He believed that operators of civil flying would not have taken that risk. Thus there might be factors in civil aviation which would decrease regularity as compared with a Transport Command operation.

The necessity to operate frequent services on routes of varying range in civil airline operations forced attention to the employment of more types of aircraft than were used in Transport Command. He felt that the operation, referred to in the paper, of the York as the only type of aircraft must have been almost ideal. But where it was necessary to use a multiplicity of types and sizes of aircraft on a multiplicity of routes, varying in range, difficulties arose. What were Air Marshal Cochrane's views as to how far maintenance troubles and the difficulties of administration generally were increased with an increasing number of types of aircraft?

Air Marshal Cochrane: Transport Command passengers were, in the main, flying on military duty, and he was afraid they were given little comfort. but nothing could be done about it. The machines must all be convertible at short notice to carrying freight and this requirement precluded elaborate furnishings.

As to the difficulties of administration when using a number of types of aircraft, Transport Command had had a great many different types, including Liberators, Yorks, Halifaxes, Dakotas, and so on, in service at the same time.

The provision of spares, and the organisation of repairs proved a serious problem. In big operations administrative factors nearly always set a limit to what could be done, and any neglect of administration was bound to prove serious.

The President: He was much impressed by the record which had been given of the great growth of traffic at a time when the people concerned must have already experienced many strenuous years of work and when resources must have been severely strained. The low accident rate, in spite of that vast increase of traffic, was amazing. Of course, he would not cast aspersions upon the operators by saying that they had achieved such success by reason of the good aircraft they had used, although that would be the natural corollary, judging from some of the remarks that had been made. Further, they had managed to achieve it even without any spares, for he understood that the spares were delivered mainly after, and not during, the war! He believed the real reason why people had had no spares was simple; they were not ordered! That might appear to be a stupid remark. But, as a matter of fact, it was generally the case that aircraft were ordered in numbers sufficient for the operations to be carried out and for the reserves to be held in order to ensure that those operations could be carried out. At a later date, when an assessment was made of the spares that had to be ordered, the orders were placed.

Supposing a hundred aeroplanes were being built, and there were in those aeroplanes two particular kinds of forgings of which spares ought also to be held. The manufacturer might even have the foresight —a virtue which some manufacturers had— to order a number of forgings additional to those actually required for the aircraft. Generally it was difficult to assess the likely requirements of spares. The position was different from that of the manufacturer of motor cars, who, having a spares and service department, could assess the likely demands in the future by reference to his previous supplies to customers. In the case of aircraft there might be, for example, a hundred sets of parts for a hundred aeroplanes, and perhaps three or four months later the manufacturer would receive a demand for a further half dozen of some parts. But the man who had stamped all the forgings from the original order would not put his tools into the stamp again merely to produce another half dozen forgings. Therefore, the order for the half dozen was put on one side. Thus, it was a fair comment that the reason why spares were not coming out of the works in the numbers in which they should, at the time they should, was often that they were not ordered.

Accidents arose from either one of two kinds of equipment; one being the "dead" equipment, represented by the aircraft and its accessories, and the other being the live equipment, *i.e.*, the personnel operating the aircraft. When the Gorell Committee made its investigations it was found that the whole of the attention of Government Departments controlling civil aviation was focused on a few manufacturers in this country who designed and made aircraft, and that when aircraft emerged from the works there was little control over what was done in regard to it in the intervening periods between each successive renewal of the certificate of airworthiness. Further, by far the greatest number of accidents were due to piloting errors, errors of judgment and the like, and very few to lack of airworthiness of the aircraft. The paper by Sir Ralph Cochrane rather bore out the point that most accidents were due to the personnel operating the aircraft.

If the pilots and other members of the crews were considered as being, after all, pieces of equipment, they needed to study them much more than they did at present. A pilot, for example, ought to undergo frequently those funny psychological tests in

which he would be required to pick things up and put them into different holes, and so on, to ensure that his mental balance was not being upset by flying, that his reactions were quick, and so on. After all, the human equipment broke down more frequently than anything else, and made errors of judgment; thus, they needed to bestow more care on that human equipment.

That led to a consideration of the noise problem and he urged that the conditions for the pilot should be luxurious. If the pilot were the most delicate piece of equipment and the most liable to break down, the conditions under which he worked should be made extraordinarily good.

There should be powers to prevent people writing about the cause of an accident on the day after it had happened, giving their reasoning, and so forth. It had been put to him recently that it was not right that, for purely commercial considerations, machines were being flown with loads far in excess of those at which they were safe to fly. That arose from writings in the newspapers, from a purely *ex parte* statement by a newspaper man. Surely it was right to await the result of the judicial enquiry. In a law case where a man was on trial for his life, or when an ordinary civil case was being conducted in the Courts, any attempt to reach a conclusion in advance of the judgment by the Judge rendered one liable to proceedings for Contempt of Court. Similarly, it should be laid down that people must not comment and give their decisions in regard to accidents which had involved loss of life unless and until a judicial enquiry had been held and a proper decision reached.

The Royal Aeronautical Society, as shown by its Proceedings, endeavoured to do things on the right basis. It was most essential nowadays that in all those matters they were guided by pure reason and not by emotion. The approach of science to the solution of any problem was to apply reason to ascertained facts, and on those ascertained facts to give an opinion. The trouble in regard to aviation and in the wider field of politics today was that some people, without troubling to find out the facts, formed an opinion because someone whom they thought was sure to be right had told them about it. A decision should be approached with a real appreciation of the underlying basis of things.

He made those remarks particularly in regard to aviation because, if one little thing went wrong with an aeroplane and one person had to deal with it and occupied perhaps a week in putting it right, about a million people would know about it by the end of the week; the aeroplane would be regarded as being of no use, everything having gone wrong.

A good instance of the difficulty was provided by the Dakota, which had probably flown far more miles than any other type and had a wonderful record of service during the war. Because there were so many of them in service, it was natural that they should sometimes meet with accidents. One heard people say they did not mind flying, but that they would not fly in a Dakota. A more stupid result could not be conceived, and it was due to emotion, instead of pure reasoning, being allowed to influence judgment.

Dr. H. Roxbee Cox (Vice-President, Fellow), *contributed*: He was glad to note the attention the lecturer gave to matters affecting the transport aircraft crew.

He agreed with him on the necessity for smart appearance. A passenger would generally assume that a smart and efficient-looking crew was smart and efficient, and feel happier in consequence. Moreover, he would generally be correct in his assumption. It must be admitted that some smart-looking people did not project their meticulousness beyond their persons, and that many people meticulous in their work pesented a shaggy front to the world. But a set of standards which demanded outward and visible sign of inward and technical competence was best

calculated to enhance both crew and passenger morale.

This virtue of smart appearance must be extended to the aeroplane itself. No traveller cared to see an aeroplane streaked with oil. He distrusted a vehicle which leaked, particularly if he suspected that the leakage was something inflammable. It was, he thought, easier to achieve oil tightness in a gas turbine than in a piston engine, so in the future there should be less excuse than ever for the untidy aircraft.

The jet propulsion gas turbine in particular could also play an important part in reducing crew fatigue, to which the lecturer drew particular attention: the simplicity of its control would tend to reduce cockpit complication, it induced practically no vibration, and it could be installed so that the crew, and indeed most of the passengers, could not hear it. These reasons, even without the more purely engineering arguments in its favour, provided a strong case for the jet-propulsion engine.

Air Marshal Cochrane: He agreed that the onus for much that went wrong could be attributed to the pilots, but he was not sure that they were not asking the pilots to do too much. Although it was true that an aeroplane seldom broke up, there was a lot more to it than that. What was necessary was to give the pilot and the whole crew a much easier task, and that called for a great expenditure of brains and ingenuity, particularly in design work. He felt that the pilot was blamed in far too many cases for an error of judgment when the operating conditions were really at fault. Anything they could do to simplify the task of the pilot they must do; they could not be satisfied with the present position.

On the motion of the President, the hearty thanks of the meeting were warmly accorded the author.

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MECHANICAL VIBRATION AND AEROELASTICITY

by

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1. Introduction.

IN his article "The Expanding Domain of Aeroelasticity,"* Professor Collar explains how, in the course of a few years, the subject of aeroelasticity has grown from a mere collection of problems of common interest to the aerodynamicist and the structural specialist to become a main branch of aeronautical engineering. Aeronautical engineers owe Professor Collar a debt of gratitude for defining in the clearest terms what aeroelasticity purports to be, and for removing the vagueness and uncertainty which so often permeates any new branch of science or engineering, especially when it is derived from long-established subjects, as aeroelasticity is from aerodynamics and theory of structures.

As is to be expected from one so distinguished in the aeroelastic field, Professor Collar writes especially from the standpoint of the aeroelastic specialist. Engineers with a different background, while accepting the broad principles which Professor Collar lays down, may see their applications and development in a different light. In particular they are likely to view with more concern than Professor Collar shows, the tendency for aeroelasticity to expand and to encroach upon the territory of other specialists. On the borderland of pure aeroelasticity there is undoubtedly much common ground which interests various types of aeronautical engineers, particularly the respective specialists of aerodynamics, theory of structures and aeroelasticity. But each of these approaches the common problems by a different route and is able to make a unique and characteristic contribution of knowledge and experience. Clearly, therefore, the general aim should be to foster co-operation, rather than encourage colonisation and expansion by the aeroelastic group of workers.

Emphasis is given here to this divergence of opinion on the expansionist policy of the aeroelastician because the present article is concerned with what might appear to be an exception to the general rule that aeroelasticity has expanded quite enough. Mechanical vibration, it is considered, should be brought entirely within the aeroelastic domain. This conclusion is reached in the course of a review of the whole position of mechanical vibration in relation to aeroelasticity and allied subjects.

The conclusion is qualified by a further consideration arising out of the same review. It is thought that the aeroelastic picture does not show mechanical vibration of the air-

*Journal of the Royal Aeronautical Society, August 1946.

frame in an entirely true light. It is in all respects as fundamental as flutter. To make it appear merely as outlying territory of aeroelasticity is to under-rate its importance and to ignore its unique scientific aspects. The amalgamation of the two subjects, therefore, should be on the basis of equality and not merely as an expansion of the aeroelastic domain.

The whole case for amalgamation of the subjects of aeroelasticity and mechanical vibration may be stated in a few words. The aeroelastic specialist has a major contribution to make to mechanical vibration. Conversely, he needs the help of the mechanical vibration specialist, especially in his experimental technique. Before either subject can be applied to a particular aircraft, moreover, much work has to be done to obtain basic data which is common to both; and the degree of overlapping interest is considerable. Finally, it is not possible to draw a clear line of distinction between the two subjects, and the generally accepted definitions lead to anomalies in practice.

Effective progress in the two subjects, in fact, is considered to require the united efforts of both types of specialist, an objective to be attained only by the complete fusion of interests.

2. Mechanical vibration.

In general engineering mechanical vibration is an every-day phenomenon. In aeronautical engineering, although of the same basic character it has acquired a rather special significance. The term "mechanical vibration" is usually taken to mean the state of vibration of the complete aircraft under the influence of mechanical pulsations, such as are produced by engine impulses and out-of-balance forces. Local and internal vibrations of an engine, or other similar self-contained component, are usually regarded as a separate subject. They are outside the scope of the present discussion, except in so far as they are transmitted to the airframe.

Mechanical vibration thus defined has clearly a close relationship to flutter, which, in general, may also be regarded as a form of over-all airframe vibration. Here the similarity ends, however, and there are several detail points of difference that are to be discussed subsequently. For the purpose of a general survey it is sufficient to remark the main distinction, namely, the entirely different sources of energy by which the respective states of vibration are excited and sustained. Thus flutter depends upon aerodynamic forces and mechanical vibration upon mechanical pulsations.

The aeroelastic approach to the two forms of vibration does not reveal the subject of mechanical vibration in its true proportions. The Collar diagrams, of which the relevant portion is reproduced here in Fig. 1, show

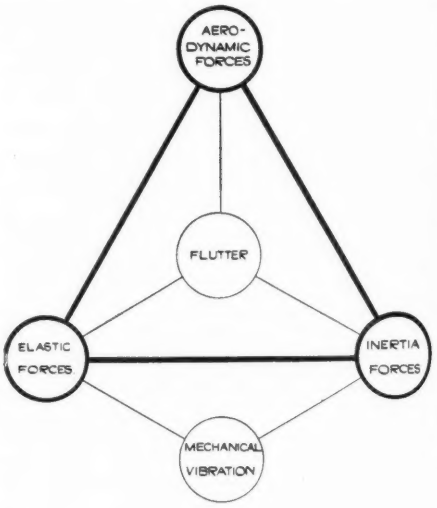

Fig. 1.
The aeroelastician's viewpoint showing mechanical vibration as outlying territory of the aeroelastic domain.

mechanical vibration as outlying territory of the purely aeroelastic domain. Flutter is securely fenced in by a triangle whose vertices are the three fundamental force systems, aerodynamic, elastic and inertia. Mechanical vibration appears outside this

triangle with connections to the elastic and inertia forces. The absence of aerodynamic force is thus emphasised, while the existence of mechanical pulsations receives only casual mention.

The broader and more general engineering approach shows mechanical vibration in an entirely different light. The mechanical pulsations appear in all respects as fundamental and as important as the aerodynamic forces are in flutter. Thus, mechanical vibration has its own triangular domain, with vertices in the mechanical, elastic and inertia force systems.

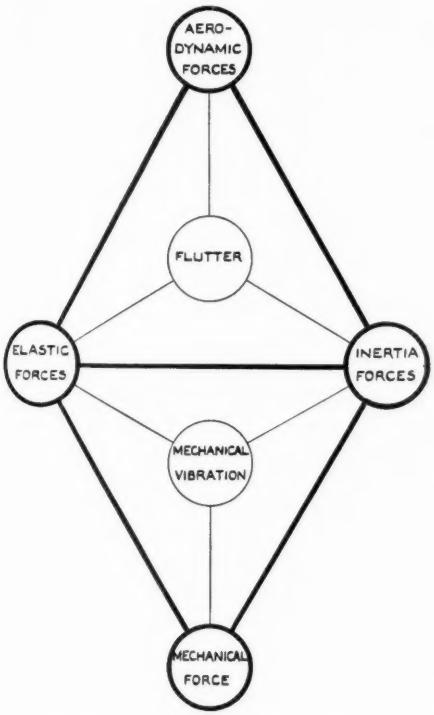

Fig. 2.
The broader engineering viewpoint showing mechanical vibration with its own fundamental triangle.

It is still possible to connect the two domains but on a basis of equality, through their common base formed by elasticity and inertia. This is shown in the alternative diagram in Fig. 2.

It is necessary to remark at this stage, therefore, that although the fusion of mechanical vibration and pure aeroelasticity is being put forward as an objective, this fusion should not be regarded as a mere extension of the aeroelastic domain. The two subjects have, in fact, developed along independent lines and each has its own special problems. The main argument is that they have too much in common for them to continue independently as subjects for specialised study.

3. The history of flutter.

Flutter became the subject of major scientific interest at a critical time in the history of aviation. Grave concern was felt at a series of rather obscure accidents producing complete loss of the aircraft. The problems presented by these accidents aroused the interest of some of the ablest scientists concerned with aeronautics. They were given every possible encouragement and assistance in their work.

The immediate result of their efforts was that flutter ceased to be a complete mystery, but the seriousness of the potential danger to all aircraft was revealed, particularly in view of the general tendency towards increase of speed. Eventually flutter became almost an exact science. The speed at which flutter would occur on a specific aircraft type could not, it is true, be predicted precisely, but it became possible to assess the probable error and to stipulate safe speed restrictions.

In parallel with the work of prediction was the development of means of flutter prevention not incurring the penalties of flight restriction. Aileron mass-balancing for prevention of flexural-aileron was introduced early, and later extended to all control surfaces and many other forms of airframe distortion. Stiffness criteria were also laid down for the *ab initio* design of new aircraft and have since undergone continuous revision with expanding scientific knowledge and practical experience.

At the present time, although entirely new aircraft forms and increased speeds are introducing new problems, the risks of flutter occurring on conventional types are not disproportionately high compared with other flying hazards.

4. THE HISTORY OF MECHANICAL VIBRATION.

The investigation of mechanical vibration has followed quite a different course. Behind it there has not been the incentive produced by serious risks of life and aircraft. Mechanical vibration seems always to have been regarded as an inconvenience, or even a nuisance, but rarely as a potential cause of catastrophic accidents. Coupled with this attitude there seems also to have been a tendency to regard mechanical vibration as a less interesting and a less difficult subject for scientific study.

It is now becoming increasingly realised that mechanical vibration of an aircraft can be catastrophic. A small component such as an oil cooler, for example, may fail through vibration fatigue and cause the aircraft to be lost. On a very long flight the additional strain on the pilot might cause a fatal error of judgment. In any case, it is now questioned whether the degree of risk of fatal accidents should exercise such a profound influence on the effort expended on the solution of a scientific problem. Safety will always be an essential objective for aeronautical engineers, but this is no reason for neglect of adverse phenomena which produce, on a conservative basis, so much wear and tear of men and material. In civil aviation, especially, attention to comfort must be given and when the problem of noise suppression is solved, mechanical vibration may take first place as a source of discomfort

The general attitude towards mechanical vibration is reflected in the way this has been dealt with in practice and the results achieved. The scientific work which has been done in the past has been mainly effective in curing vibration trouble only after it has occurred on a completed aircraft. The resulting modifications to the type, particularly when it has already been in production, have frequently been difficult. Sometimes only a compromise has been possible.

5. THE LESSONS OF HISTORY.

There are lessons to be learned from the contrasting histories of flutter and mechanical vibration. The incentive produced by fatal accidents through flutter has directed, and even diverted, much effort towards this subject. The apparently more mundane subject of mechanical vibration has suffered by comparison. Tribute must be paid to the pioneer work of those who have realised the importance of mechanical vibration but, by comparison, they have been too few in number and their scope restricted within narrow limits.

There is clearly a need for the same comprehensive and scientific approach towards mechanical vibration that has existed for flutter from the earliest times. The widespread belief that mechanical vibration has less scientific interest now appears to be without foundation. That it is less difficult and less in need of scientific study is contradicted by facts. The occurrence of flutter can now be predicted with far greater certainty than can excessive mechanical vibration. To prevent flutter by attention to original design is far easier than prevention of excessive mechanical vibration. A serious anomaly would therefore be removed if flutter and mechanical vibration were combined with the legitimate domain of aeroelasticity.

6. THE MECHANICAL ASPECTS OF FLUTTER.

The foregoing discussion of the past history of flutter and mechanical vibration suggests that material benefits are to be gained by employing flutter specialists on mechanical vibration problems. There is another side to this story in which the flutter

investigation is seen to be dependent upon the mechanical vibration specialist. For this purpose consideration has to be given to the way in which flutter investigations are made during the various stages of design and development of a new type.

In the initial design stages of a new aircraft type, flutter can only be investigated by theoretical means. The first step in a theoretical investigation is the determination of natural frequencies and corresponding modes of deformation. The information is obtained without any reference to aerodynamic force and is purely a problem in mechanical vibration. Moreover, it is equally essential for the investigation of mechanical vibration as for flutter.

In the next stage in design and development of a new type, a prototype has been completed but has not yet flown. It is now possible to determine natural frequencies by experiment on the ground in the so-called "Resonance Tests." As with preliminary calculations, the information is equally essential for mechanical vibration and flutter investigations.

The resonance tests, however, establish a still closer link between flutter upon mechanical vibration. Since the whole aircraft is made to vibrate by mechanical means, the technique for resonance testing is essentially within the province of the mechanical vibration specialist.

7. Vibration in flight.

In the pre-flight stage the case for amalgamation of effort is based largely on efficiency and expediency. In flight, however, there is a fusion of interests brought about by natural causes.

Flutter is frequently, if not usually, catastrophic. Not only must it be avoided at any cost, but even when it occurs inadvertently there is usually little evidence of scientific value. Practical evidence on flutter is usually obtained from phenomena which may be described as incipient flutter, in which the same kind of aerodynamic force systems operate as for fully developed flutter, but in a smaller degree.

Now a form of vibration frequently occurs in flight which, although it may be severe, is not catastrophic. When occurring operationally it is usually reported upon qualitatively with reasonable accuracy, and can be reproduced experimentally with recording instruments, such as vibrographs, installed on the aircraft.

Usually such vibration is mechanically induced, but is aggravated by a degree of aerodynamic response of a kind that would at some higher speed lead to catastrophic flutter. The information obtained is usually of great value to flutter specialists and gives a still closer representation of flutter conditions than does the ground resonance test. Interpretation of the phenomenon, however, clearly requires specialist knowledge of both mechanical vibration and flutter, since the effects of both are superimposed.

Even when one or other of the two forms of vibration predominates, so that the other is virtually excluded, recognition is difficult. In theory it should be possible to establish at once whether vibration is mechanical or incipient flutter, such as by varying the engine speed. In practice this is rarely feasible and prolonged experiment followed by detailed analysis is necessary. Until the diagnosis is made, the investigator needs to be a specialist in both mechanical vibration and flutter. When the diagnosis has been made, the investigation has usually proceeded too far for it to be worth while to call in the appropriate exclusive specialist.

8. Flutter experiments in flight.

Closely related to the investigation of mild or incipient flutter as occurring unintentionally, is the deliberate excitation of incipient flutter by mechanical means. Thus the aircraft is made to vibrate mechanically at

frequencies near, but not too near, the critical flutter frequencies; and data relative to catastrophic flutter is obtained from the measured aerodynamic responses.

As before, the interpretation of observed behaviour requires a specialist in both mechanical vibration and flutter, since both phenomena are superimposed.

The mechanical vibration aspects, however, are even more strongly emphasised. The excitation of the vibration is a task for the mechanical vibration specialist. Not only does the apparatus need to be designed for installation and operation in an aircraft, but special precautions have to be taken to avoid danger. These experiments can be dangerous since, apart from the direct effects of deliberately excited vibration, there is a risk of the aerodynamic forces taking complete charge and wrecking the aircraft. The problem of control and suppression of vibration is clearly within the province of the mechanical engineer, rather than being a suitable responsibility for the purely aeroelastic specialist to undertake.

These flutter experiments appear to deserve special mention since they are one of the most promising fields for further research work on flutter and provide a strong reason for mechanical vibration to be included as an essential part of the subject of aeroelasticity.

9. Damping forces.

In the foregoing discussion the case for amalgamation is mostly concerned with expediency and efficiency in attacking the various problems occurring in mechanical vibration and flutter. The broad distinctions between the two subjects are there accepted as reasonable and convenient for initial survey. In reality, however, the relationship between mechanical vibration and flutter is much closer than the method of representation indicates, especially when the effect of damping forces is taken into consideration.

It is accepted that elastic and inertia forces are common to both forms of vibration. The broad distinction lies in the third force system, which for flutter is aerodynamic and for mechanical vibration is mechanical. This distinction is correct, however, only in respect of primary exciting force and not in respect of damping force. Now the aeronautical engineer is interested in mechanical vibration and flutter mainly from the standpoint of preventing or controlling them, and the dissipation of destructive energy may be as important as preventing it from being generated.

Aerodynamic damping force can be a major factor in mechanical vibration. Perhaps its importance has been neglected, but there can be no doubt that the vibration level of many aircraft is kept within acceptable limits mainly through aerodynamic dissipation. The same aerodynamic and mechanical process which may translate mechanical energy into incipient flutter can also act as a suppressor. There have been cases where the difference in the severity of mechanical vibration on two similar aircraft could only be explained in this way. Thus it is that the mechanical vibration specialist cannot ignore aerodynamic force, and aerodynamics is not exclusively the province of the pure aeroelastic specialist.

The converse, by which flutter is dependent on mechanical damping is perhaps not so strong. Structural damping is a mechanical force and can be amplified by mechanical means, but at present it does not appear important in relation to flutter prevention. In principle, however, the relationship is there and conditions may change in the future.

Consideration of damping, therefore, indicates that although flutter and mechanical vibration may be distinguished by these different modes of excitation and generation of energy, they are cross-linked by their dependence on the alternative force systems for damping and dissipation of energy. This connection thus provides an additional reason for the two subjects being merged together.

10. ARTIFICIAL BARRIERS.

Even apart from damping, the attempt to distinguish between flutter and mechanical vibration is more arbitrary and inconsistent than might be supposed. In practice the working distinction does not follow the Collar plan, or any other simple plan.

Vibration caused by interference with the airscrew flow of air, or by the aerodynamic inequalities of the airscrew blades, is unquestionably excited by aerodynamic force. In accordance with the broad definitions behind the Collar diagrams, therefore, such forms of vibration appear to lie in the purely aeroelastic field. The pulsations, however, are regular and are related to the engine speed. For all practical purposes the vibration resembles mechanical vibration and is invariably treated as such.

Tail buffeting is an example of the opposite kind. The excitation, although aerodynamic because it is produced by the wings, is virtually independent of the response of the tailplane and the characteristics of the vibration closely resemble mechanical vibration. Yet tail buffeting is classed with flutter as lying within the aeroelastic field.

It is of interest to remark on a fairly precise distinction which may be drawn between two forms of vibration. In general, vibration might be classified according to whether the excitation is direct or coupled. Thus, ideally at any rate, one exciting system would function independently of the effect it produces; and the other would be modified, and usually amplified, by the response. It so happens that mechanical vibration, as usually understood, comes broadly within the first class and flutter in the second. The distinction, however, can have little practical value since specialists in both mechanical vibrations and flutter should be fully familiar with both direct and coupled excitation.

These anomalies and inconsistencies, as well as the absence of any precise and general distinction, serve to emphasise how artificial the present separation really is of aeroelasticity and mechanical vibration.

11. CONCLUSIONS.

The broad conclusion is reached that when flutter and mechanical vibration are regarded as comparable subjects their amalgamation is imperative. In the past, benefits would have been gained if this amalgamation had taken place earlier. For the future, there are indications that fusion is becoming increasingly necessary and ultimately may be unavoidable.

Benefits are to be gained by applying to mechanical vibration the scientific methods and degree of effort that have always been associated with flutter. The catastrophic nature of flutter has focused disproportionate attention upon it, while the apparent innocuousness of mechanical vibration has encouraged an undesirable complacency.

On the other hand, the flutter specialist is becoming increasingly dependent upon the mechanical vibration specialist for the technique of his experimental work. Much of the work embraced by mechanical vibration, moreover, is equally applicable to flutter.

BOOK REVIEW

Proceedings for the Society for Experimental Stress Analysis. Volume IV, Number 1.

Published by Addison-Wesley Press Inc., Kendall Square, Cambridge, Mass. Price $6.

Volume Four of the "Proceedings for the Society for Experimental Stress Analysis" begins with three articles on the reduction of rosette strain gauge measurements by graphical

or nomographical methods to obtain the principal stresses and their directions. The first of these papers is notable for its directness and simplicity, but the nomographical methods of the two following papers strike one more by their over-elaborated ingenuity than by their practical value.

There follows an interesting paper on the photoelastic analysis of a spar bulkhead. The application of photoelastic technique to such a large aircraft component certainly deserves the attention of aircraft designers. People concerned with the design of high pressure vessels will be interested to find an article describing the difficult technique for the electrical measurement of strains on the inside of such closed vessels.

One of the most important articles in this volume is concerned with the measurement of residual stresses in torsion bar springs. The pre-setting of torsion bar springs leads to great economy in weight and material, and the purpose of this paper was to find out if the pre-setting is maintained throughout the service life of the spring. The reviewers were particularly impressed by the elegant technique of measuring residual stresses by machining off successive layers and measuring the resulting twist.

A short but excellent article follows, giving a quick method for the qualitative determination of residual stresses by applying brittle lacquer and subsequently drilling holes in the material.

The next paper gives a method for determining the stress distribution through a beam or shell when only the outside surface is accessible. Mechanical gauges are employed and the method pre-supposes a linear stress distribution across the section.

The possible loss of efficiency, due to lateral buckling under impact, of the long slender tools used in the percussion drilling of rock, forms the subject of the next paper. An excellent account of the experimental methods used is followed by some interesting theoretical analysis.

The paper on the pressure of plastic concrete in forms may be recommended to engineers in this field.

The volume concludes with an account of the adaptation of the electrical strain gauge to give stress readings directly in materials of known Poisson's ratio.

The full list of articles is as follows: —

A Graphical Method of Rosette Analysis.
A Nomographic Solution to the Strain Rosette Equations.
A Nomographic Rosette Computer.
Photoelastic Analysis of a Spar Bulkhead in a Semi-Monocoque Airplane Fuselage.
Stress Study of a Fabricated Steam Chest.
New Portable Stress Analysis Equipment.
Measurement of Residual Stresses in Torsion Bar Springs.
Residual Stress Indications in Brittle Lacquer.
Mechanical Strain Gage Technique of Separating Strains Due to Normal Forces and Bending Moments.
Impact on Prismatical Bars.
Pressure of Plastic Concrete in Forms.
The Stress Gage.

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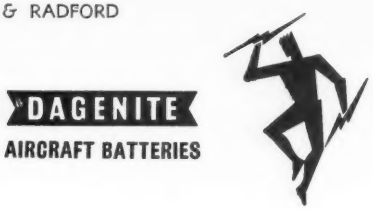

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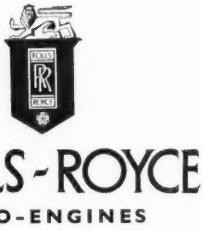

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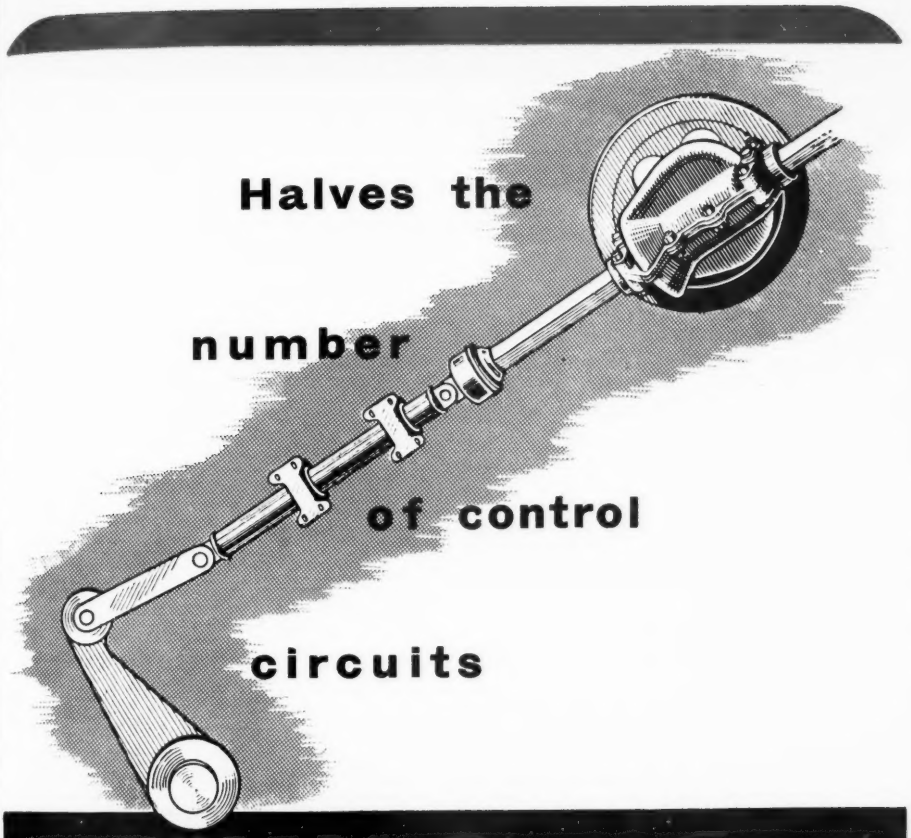

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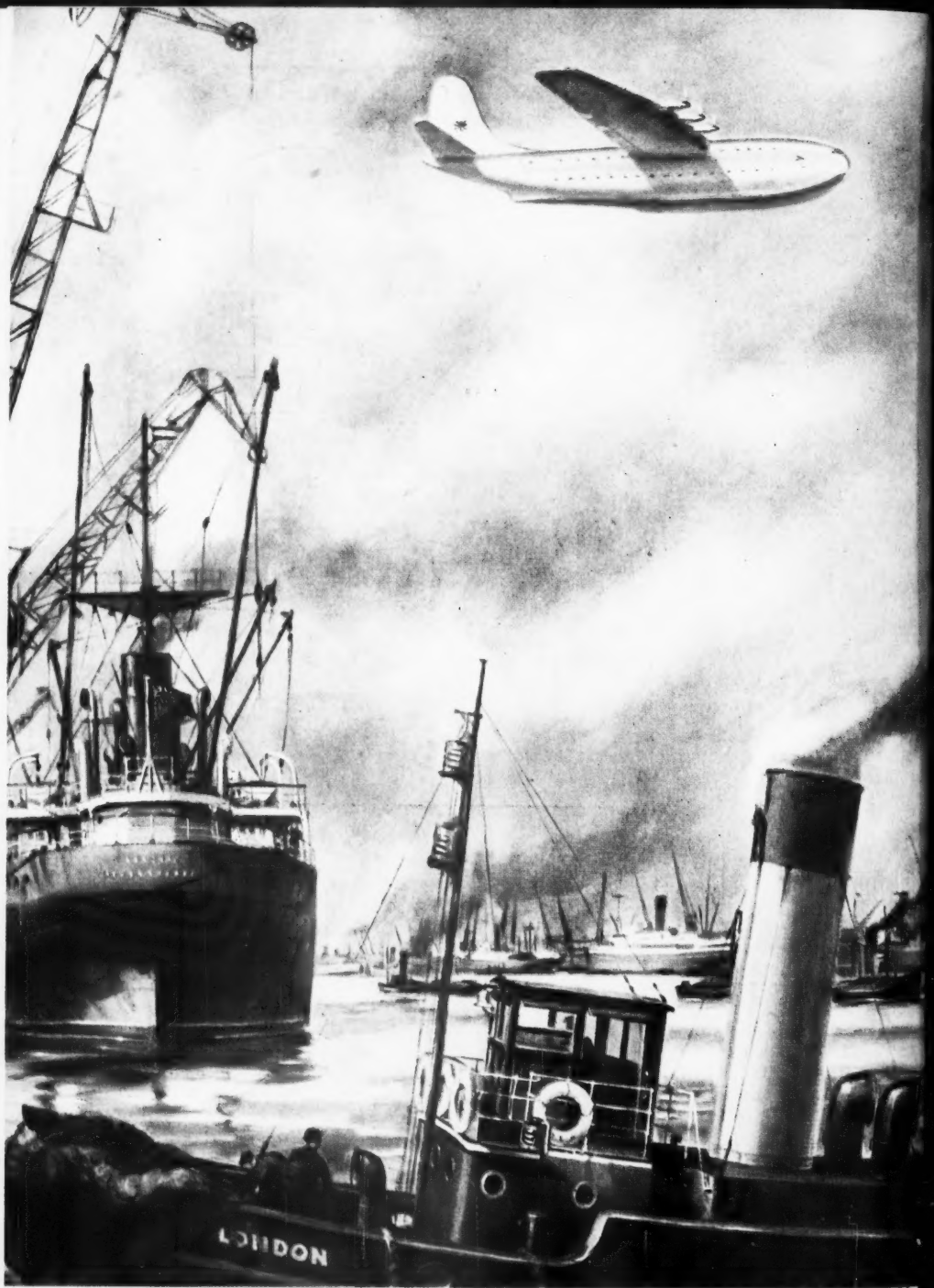

A Saunders-Roe Flying Boat over London Docks *Painted by C. H.*

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